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Permian carbonate facies of the Franson member Phosphoria formation southwestern Montana

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PERMIAN CARBONATE FACIES OF THE FRANSON MEMBER,

PHOSPHORIA FORMATION,

SOUTHWESTERN MONTANA

by

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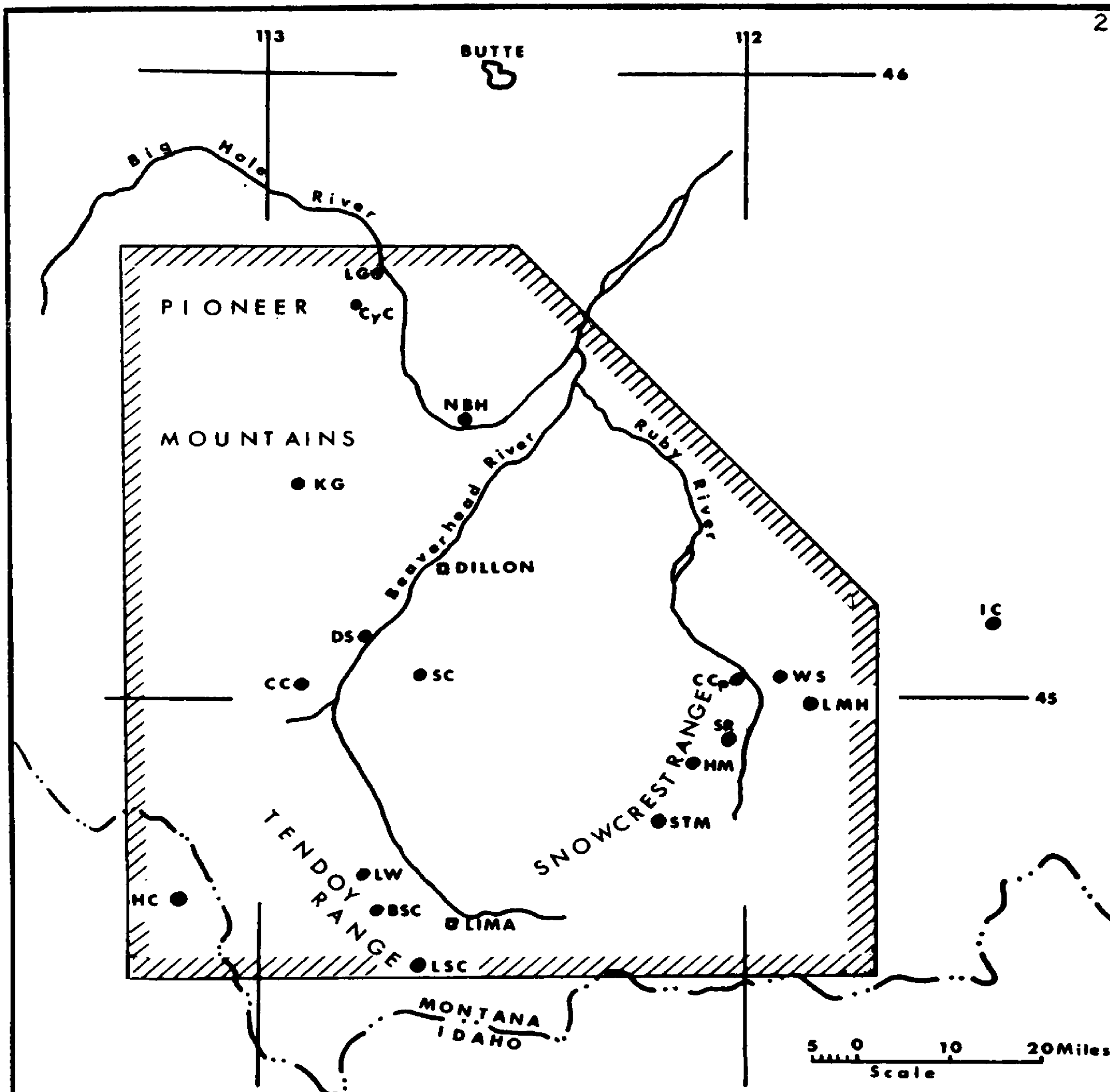
INTRODUCTION

The purpose of this investigation was to define and interpret the depositional environment of the Permian carbonate facies of the Franson Member, Phosphoria Formation, in southwestern Montana (Figs. 1 and 2). This study represents a northern extension of work done in southeastern Idaho by Brittenham (1972), and in Wyoming by Ahlstrand (1971) and Cole (1970), all of whom have contributed to a regional Permian carbonate facies study supervised by Dr. James A. Peterson.

Study Methods

The Franson Member was measured, sampled, and described at seventeen localities in southwestern Montana (Fig. 1) during the summers of 1970 and 1971. At four of these sections, Cedar Creek, Canyon Creek #3, La Marche Gulch, and North Big Hole Canyon, the Phosphoria Formation was measured and sampled from the top of the underlying Quadrant Formation to the base of the Retort Member. Outcrop description emphasized fossil content, sedimentary structures, chert occurrences, and the type of contact between lithologically distinct units.

Thin sections were cut from 735 samples and petrographically examined for the following features:



BSC - Big Sheep Canyon	LG - La Marche Gulch
CCp - Canyon Camp	LMH - Lazyman Hill
CyC - Canyon Creek #3	LSC - Little Sheep Creek
CC - Cedar Creek	LW - Little Water Canyon
DS - Daly's Spur	NBH - North Big Hole Canyon
HC - Hawley Creek	STM - Sawtooth Mountain
HM - Hogback Mountain	SC - Sheep Creek
IC - Indian Creek	SR - Sliderock Mountain
KG - Kelly Gulch	WS - Warm Springs

Fig. 1 - Index Map showing outline of the study area and localities of the measured sections.

a. texture - relationship of grains to matrix

b. clastic grains - type, size, and percentage

c. structure - such as laminating, burrowing, scouring

d. organic remains

e. alteration - such as dolomitization, silicification, phosphatic replacement

f. porosity

Previous Work

The Permian Phosphoria Formation generated considerable geologic interest in the western United States following World War II. Oil fields were discovered in the Phosphoria Formation in Wyoming, while in southwestern Montana, southeastern Idaho, Wyoming and Utah interest centered on the uranium, vanadium, and phosphate found in the phosphatic members. Permian phosphorites were discovered in southwestern Montana by Gale (1911), and subsequent work of the U. S. Geological Survey, and others, was concentrated on the economically important phosphate members. Cressman and Swanson (1964) summarized most of the work done by the U. S. Geological Survey on the phosphate deposits in southwestern Montana, and their publication was used as reference material for the present study.

REGIONAL GEOLOGY

Regional Geologic History

The Cordillera was influenced by geosynclinal deposits throughout the Paleozoic. Tectonism climaxed during the Pennsylvanian, and, as activity decreased in the Permian, former high positive areas were reduced to low relief or buried with sediments, and negative areas, which earlier in the Paleozoic were deep and sinking, became filled and stable. This resulted in a broad, stable marine shelf in the eastern or shoreward areas of the geosyncline during the Permian (McKee, Oriel, and others, 1967).

The Cordilleran geosyncline was divided into two areas; a western eugeosyncline or trough province, and an eastern miogeosyncline and shallow shelf province. The western eugeosyncline was filled with thick marine volcanic deposits from a volcanic archipelago in the vicinity of the present west coast. The eastern province was dominated by sandstones, shales and limestones, which were deposited over a broad shallow shelf covering northern Utah, eastern Idaho, western Wyoming, and southwestern and south central Montana (Eardley 1951). The Permian Phosphoria Formation was deposited across this broad shelf in a series of transgressions and regressions. Scholten (1957) suggested that the shallow Permian shelf deposits were separated from the equivalent miogeosynclinal rocks of the Casto Volcanics, found near Orofino, Idaho, by an active hinge line located just west of the present Montana-Idaho border (Fig. 2).

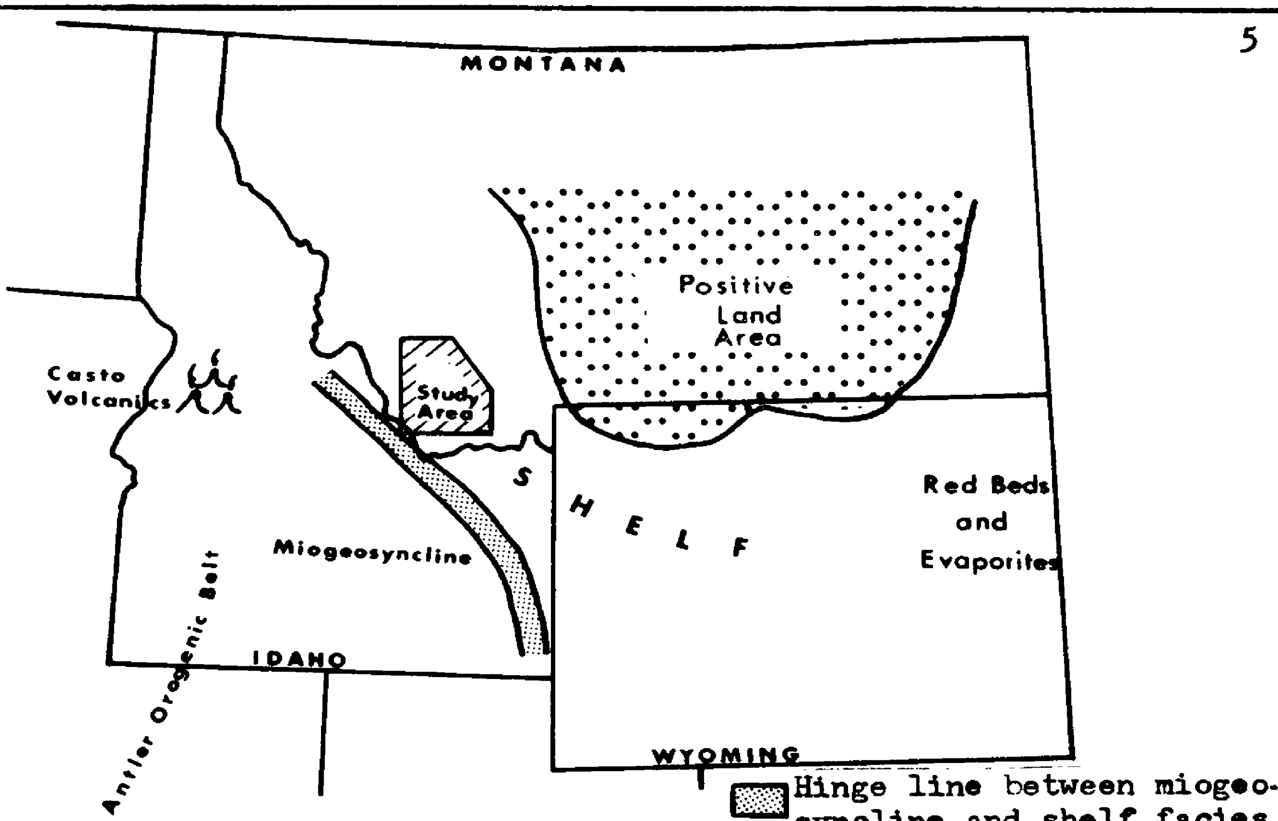


Fig. 2 - General regional distribution of Permian rocks and tectonic elements. Adapted from Swanson (1970).

During the late Cretaceous and early Tertiary, structure in southwestern Montana was influenced by the Laramide Orogeny which deformed pre-Cenozoic rocks into tight folds, thrusts and low-angle faults west of the Beaverhead River and into more broad and open folds and high-angle faults to the east.(Cressman and Swanson 1964).

Palinspastic Considerations

Structural movement of the rocks must be considered in reconstructing the geometry of the basin of deposition for the Franson Member, as tight folds and thrust plates in southwestern Montana have displaced some sections as much as 25 miles. In the Tendoy Mountains, several thrust plates with a northeasterly direction of movement have been identified by Scholten (1957) and can be traced northward along strike to the vicinity of Clark Canyon Dam. In the Pioneer Mountains, thrusting of pre-Cambrian rocks to the east has pushed Upper Paleozoic sediments into tight folds; while deformation in the eastern portion of the study area is more gentle, as expressed by the broad folding of the Ruby River overturned syncline.

In constructing the palinspastic maps, sections associated with the Tendoy Mountain thrust plates have been moved twenty-five miles to the southwest, while the Cedar Creek section, which was affected by the northern extension of these thrusts, has been moved fifteen miles to the west-southwest. Reconstruction of the folded areas resulted in a western displacement of two miles for those sections located on the western limb of the Ruby River overturned syncline, and in a westward movement of two miles for the Canyon Creek #3 and Kelly Gulch sections in the Pioneer Mountains. All subsequent maps and cross sections are based on the palinspastic locations. in Fig. 3.

Permian Stratigraphy and Nomenclature

Permian rocks in southwestern Montana, southeastern Idaho, Wyoming, and Utah are assigned to the Phosphoria Formation. In southwestern Montana, the Phosphoria Formation consists of four major rock types: chert, dolomite, sandstone, and interbedded phosphorite

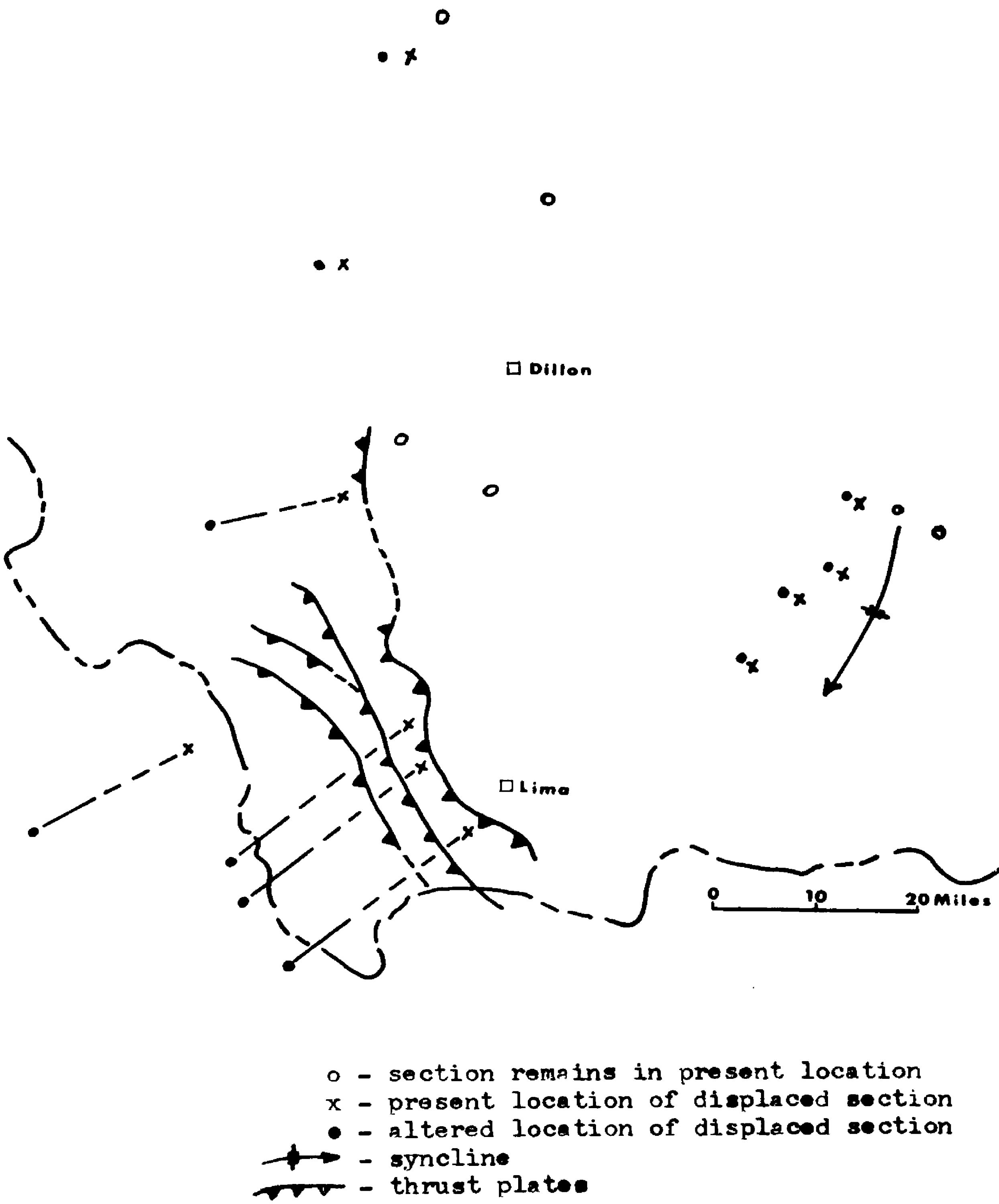


Fig. 3 - Palinspastic map showing displacement of the sections adapted from Scholten (1957).

and dark mudstone.

Nomenclature for Permian rocks, as adopted by the U. S. Geological Survey for the Western Phosphate Field, assigned formational status to the various lithologically distinct units mentioned above (McKelvey and others, 1956). In southwestern Montana, carbonate units were included in the Park City Formation and were divided into the Grandeur Member and the Franson Member. Grouped under the Phosphoria Formation were the chert units of the Rex and Tosi Members, and the phosphate units of the Meade Peak and the Retort Members. Sandstone units were assigned to the Shedhorn Member. Conversely, petroleum workers have combined all Permian rocks into the Phosphoria Formation and assigned member or tongue status to the major lithologic units. A review of the history of Permian nomenclature in the Western Phosphate Field can be found in McKelvey and others (1956).

The terminology used in this report assigns all Permian rocks in southwestern Montana to the Phosphoria Formation. The west-east cross section of Fig. 4 shows the complex intertonguing of the various members.

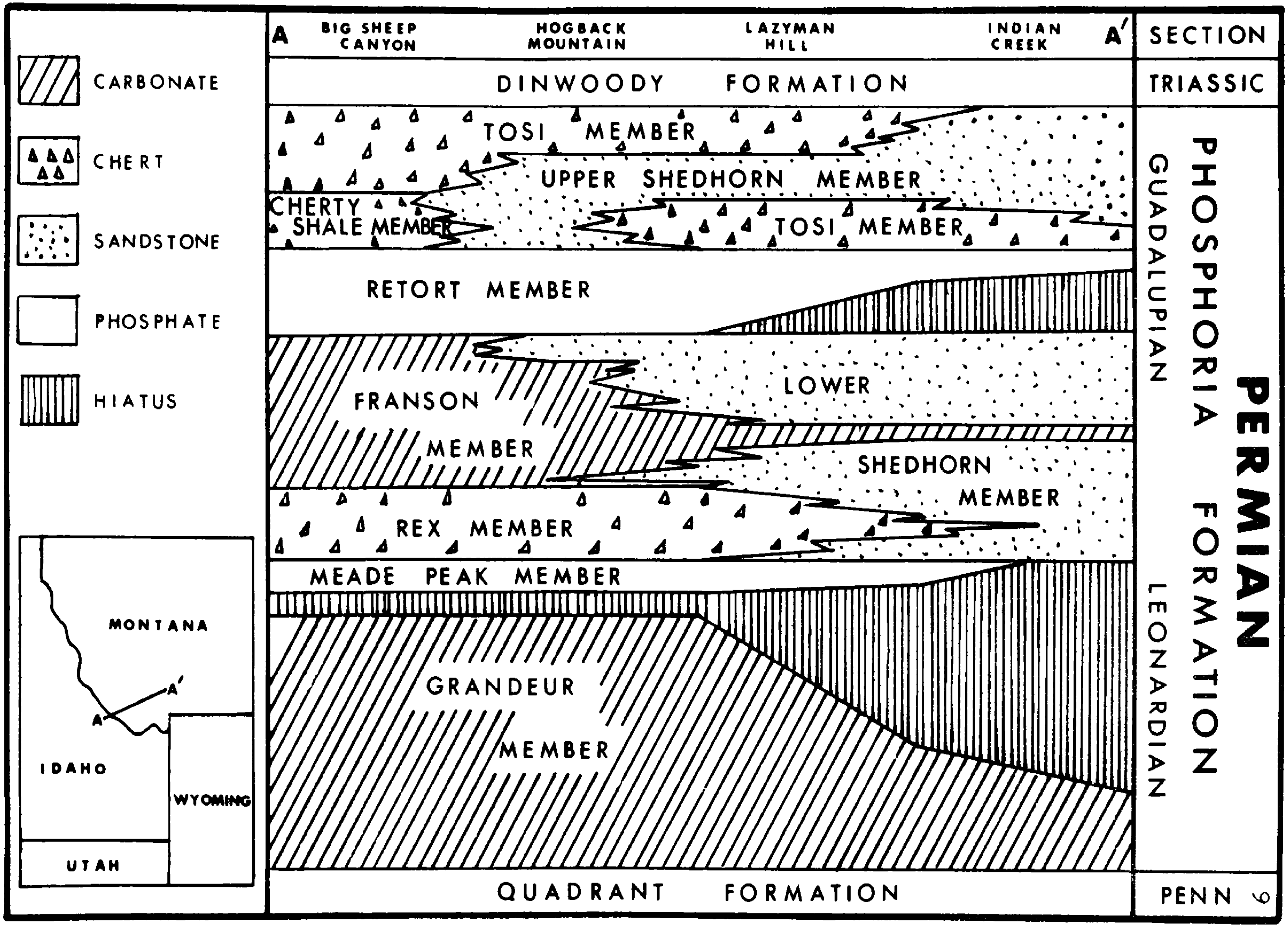


Fig. 4 - Permian Nomenclature for southwestern Montana used in this report.

STRATIGRAPHY OF THE FRANSON MEMBER

General Stratigraphy

In southwestern Montana the Franson Member is underlain by the Rex Chert Member and is capped by phosphatic shales and mudstones of the Retort Member. The Franson Member intertongues with, and is equivalent to, the lower Shedhorn Sandstone Member to the east of the study area and the Rex Chert Member to the southwest. Franson and Grandeur Member carbonates are undifferentiated in two of the northernmost sections, at La Marche Gulch and Canyon Creek #3, where the Rex and Meade Peak Members are missing. A palinspastic isopach map of the total thickness of the Franson and its equivalents (Fig. 5) shows a general thinning to the east and northeast, as the positive area of central Montana is approached.

The Franson interval was dominated by carbonate deposition across a shallow marine shelf province. The southwestern part of the study area contains shelf-edge bioclastic carbonate build-ups, while in the central and eastern portions sediments suggest deposition in a shallow protected basin. Clastic influx played an important role during the early and late stages of Franson deposition. Tongues of Shedhorn Sandstone were derived from a land mass to the east and spread out over the shallow basin during regressive phases, while a northwestern source contributed considerable clastic material to the western shelf-edge province, especially during early Franson deposition. The

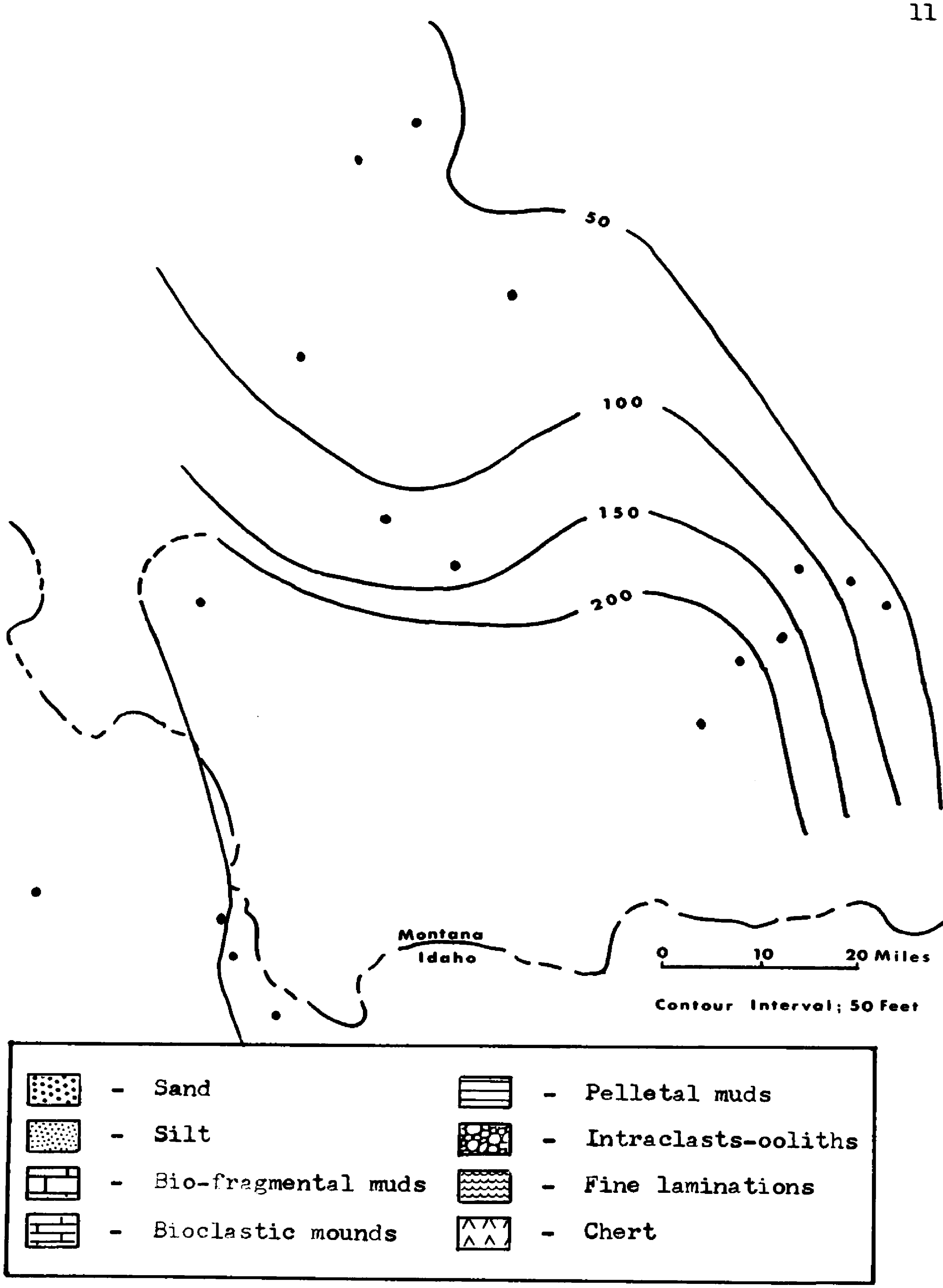


Fig. 5 - Palinspastic Isopach Map of the total thickness of the Phosphoria Formation between the Meade Peak Member and the Retort Member.

clastic influence is accented on the palinspastic net carbonate isopach map (Fig. 6) by rapidly decreasing carbonate thickness to the east and by the anomalous carbonate zero at Daly's Spur.

Correlation Criteria

Stratigraphic correlation and facies interpretation are based on the establishment of time horizons. "Time lines" are usually defined by recognition of faunal zones or by lithologic criteria, such as widespread thin beds which are interpreted to be deposited synchronously. The lack of recognizable faunal zones in Permian rocks of Montana has necessitated the use of lithologic criteria to establish time horizons (Cressman and Swanson, 1964). Some of the units used for correlation in the Phosphoria Formation are relatively thin phosphorite beds found in the Retort, Meade Peak and Rex Chert Members. Intertonguing of adjacent lithologic units, such as the Franson Member carbonates with the lower Shedhorn Member sandstones, also suggests time equivalence of the two units.

An attempt was made to establish time horizons within the Franson across the whole study area on which carbonate facies patterns could be developed. Petrographic examination of thin sections provided no reliable data for time correlation between all the sections; however, correlation within an area could often be established. Thin section evidence used for correlation includes: thin sponge-spicular beds in localized areas and the presence of phosphatic fossil fragments.

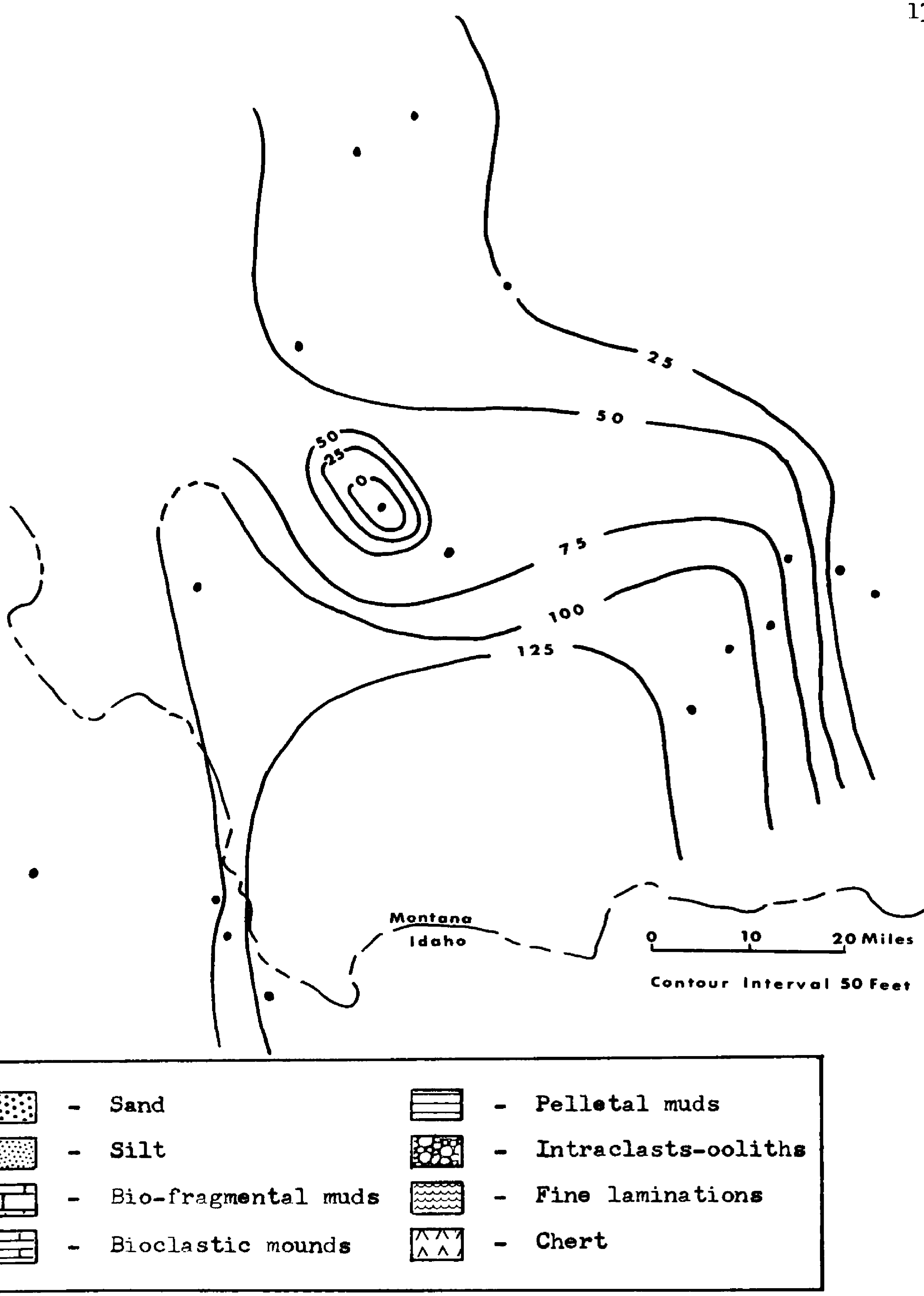


Fig. 6 - Palinspastic, net carbonate isopach map of the Franson Member.

CARBONATE AND SAND FACIES OF THE FRANSON MEMBER

Rock Classification

Rocks of the different carbonate facies are classified according to depositional textures as proposed by Dunham (1962) (Table I). In Dunham's classification the term "mud" refers to carbonate crystals with a grain size of less than 20 microns. Modifiers were added to the textural term to describe individual grain types in the rock. Dolomitization and silicification of the primary sediments prevented adequate use of Folks (1962) compositional classification.

Division of clastic material into sand and silt sizes was determined by use of Wentworth's scale (Table II).

Depositional Provinces

For clarity and simplicity of delineating the different facies, the study area was divided into two environmentally separate depositional provinces. Rocks in the eastern province suggest deposition in a shallow protected basin and shoreward area, while sediments in the western province indicate deposition within and adjacent to, an agitated shelf-edge environment. Initially, the divergent facies of these two provinces will be treated separately, but later they will be correlated to develop the depositional phases.

<table>
<tr><th colspan="5">DEPOSITIONAL TEXTURE RECOGNIZABLE</th><th rowspan="5">DEPOSITIONAL TEXTURE NOT RECOGNIZABLE</th></tr>
<tr><td colspan="4">Original Components Not Bound Together During Deposition</td><td rowspan="4">Original components were bound together during deposition... as shown by intergrown skeletal matter, lamination contrary to gravity, or sediment-floored cavities that are roofed over by organic or questionably organic matter and are too large to be interstices.</td></tr>
<tr><td colspan="3">Contains mud (particles of clay and fine silt size)</td><td rowspan="3">Lacks mud and is grain-supported</td></tr>
<tr><td colspan="2">Mud-supported</td><td rowspan="2">Grain-supported</td></tr>
<tr><td>Less than 10 percent grains</td><td>More than 10 percent grains</td></tr>
<tr><td>Mudstone</td><td>Wackestone</td><td>Packstone</td><td>Grainstone</td><td>Boundstone</td><td>Crystalline Carbonate
(Subdivide according to classifications designed to on physical texture or diagenesis.)</td></tr>
</table>

Table I. Classification of carbonate rocks according to depositional texture, Dunham (1962).

	mm			
	2.00		-1.0	
	1.68		-0.75	
	1.41		-0.5	Very coarse sand
	1.19		-0.25	
	1.00		0.0	
	0.84		0.25	
	0.71		0.5	Coarse sand
	0.59		0.75	
1/2	0.50	500	1.0	
	0.42	420	1.25	
	0.35	350	1.5	Medium sand
	0.30	300	1.75	
1/4	0.25	250	2.0	
	0.210	210	2.25	
	0.177	177	2.5	Fine sand
	0.149	149	2.75	
1/8	0.125	125	3.0	
	0.105	105	3.25	
	0.088	88	3.5	Very fine sand
	0.074	74	3.75	
1/16	0.0625	62.5	4.0	
	0.053	53	4.25	
	0.044	44	4.5	Coarse silt
	0.037	37	4.75	
1/32	0.031	31	5.0	
1/64	0.0156	15.6	6.0	Medium silt
1/128	0.0078	7.8	7.0	Fine silt

Table II. Classification of clastic grain size, Wentworth (1922).

Eastern Province

The four facies which have been identified in the eastern province are the eastern sand facies, the silty laminated facies, the pellet-intraclast facies, and the sponge spicule facies. These facies intertongue at most of the eastern sections, with the sand facies dominating in the eastern or more shoreward areas and the pellet-intraclast facies dominating in the western or more basinward area.

Eastern Sand Facies

The eastern sand facies is represented by the Franson-equivalent lower Shedhorn Sandstone Member. East of the study area the Shedhorn Member comprises nearly the whole Franson interval except for a few thin tongues of carbonate, while basinward the lower Shedhorn Member is represented by an upper and lower tongue of sand which migrated west during periods of maximum regression.

Description. The sands of this facies consist mostly of rounded to sub-rounded detrital quartz grains with minor amounts of detrital chert and phosphate grains in a calcareous matrix. The sediments are usually fine- to very fine-grained and well sorted, and the grain size becomes slightly finer as the tongues of sand are traced basinward.

In outcrop, the lower tongue is mostly thin-bedded and platy, while the upper tongue is more massive and contains a few interbeds of chert. Erosional surfaces overlain by pebble beds were identified by Shepherd (1971) in the eastern exposures of the lower Shedhorn

Member suggesting emergence and sub-aerial erosion during periods of maximum regression.

Interpretation. The lower Shedhorn Sandstone Member represents a near shore marine beach and longshore bar environment. The sand facies dominates at Warm Springs and Lazyman Hill in the eastern part of the study area, and during maximum regression in early and late Franson deposition, tongues of sand migrated basinward. Detrital chert and phosphate grains were probably derived by reworking sub-aerially exposed rocks of Rex chert and Meade Peak phosphate on the periphery of the basin.

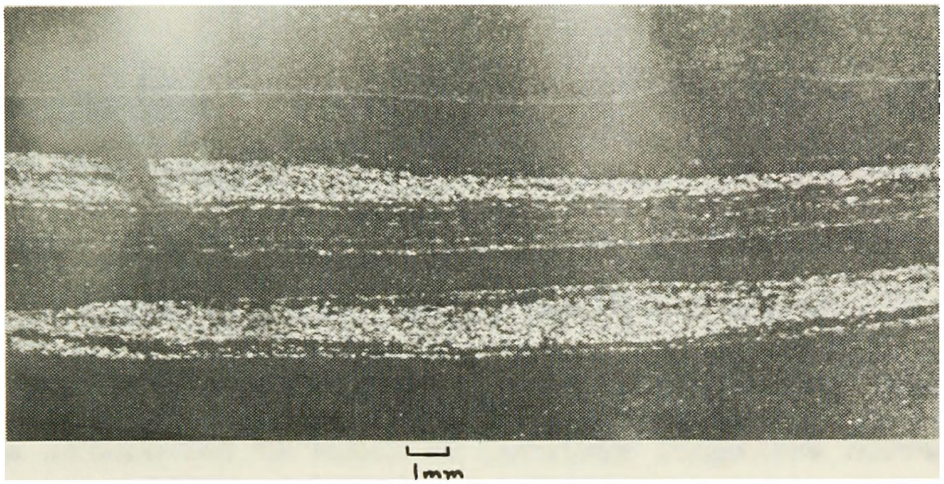
Silty Laminated Facies

This facies lies between the basinward pellet-intraclast facies and the shoreward sands of the lower Shedhorn Member and attains its greatest thickness at Canyon Camp.

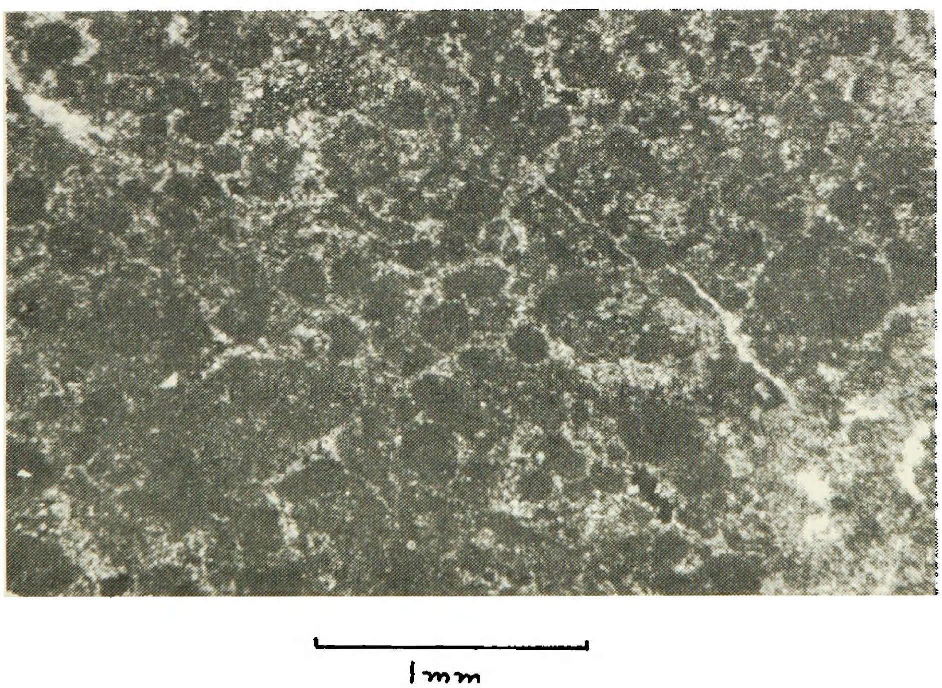
Description. In outcrop it is characteristically platy or thin-bedded, consisting of fine, parallel laminations made of silt or fine sand grains. Sand is sometimes found concentrated into thin layers, stringers and lenses, and where sand is more abundant some small cross beds and migrating ripple marks are observed. Fine, wavy laminations suggestive of organic influence are occasionally seen.

Thin sections show mostly thin, evenly laminated fine sand, silt and dolomitic mud (photo-plate 1A) plus some microscour features, small cross beds, and discontinuous sand stringers. Variance of grain size, from fine sand to mud, commonly accentuated the laminae. Some

PHOTO-PLATE 1



A. CCp-4U: Silty Laminated Facies; fine laminations of silt and dolomite mud.



B. STM-4L: Mud-Pellet Sub-Facies; pelletal packstone.

thin layers of silt associated with brown organic-appearing material may have originated from sediment trapped by filamentous algae. Some intraclastic debris is also present, usually being well-rounded and bedded.

Interpretation. Deposition of the stromatolitic(?), silty, laminated dolomites probably occurred adjacent to, and within, an intertidal zone. Intermittent influx of fine sand and silt as tides moved across an intertidal zone would account for the finely laminated dolomites. Small cross beds, scour marks, and migrating ripples could also be attributed to tidal or possibly longshore currents. Other evidence for intertidal or shallow water deposition includes the possible existence of silt-trapping, stromatolitic, filamentous algae, and the occasional occurrence of well-rounded intraclastic debris.

All the carbonates of this facies have been dolomitized. Dolomitization in an intertidal environment probably occurred penecontemporaneously (see section on dolomitization, p. 49), as evaporation of the restricted sea waters raised the Mg/Ca ratio, causing aragonite muds to be dolomitized by the Mg-rich waters. In the intertidal zones, dolomitization possibly occurred by concentrating Mg in the sediment by evaporation of interstitial waters.

Pelletal Intraclast Facies

This basinward facies can be divided into two sub-facies, the mud-pellet sub-facies and the intraclast-oolith sub-facies, whose environments differ primarily in the amount of wave agitation.

Mud-pellet sub-facies

Description. Most of the rocks in this sub-facies are fossil-fragmental, pelletal, dolomitic wackestones and packstones. Fossil fragments are commonly phosphatized, and include bryozoan, ostracod, gastropod, red algae (?), pelecypod, algal-blades, and assorted unidentified fragments. Fecal pellets (photo-plate 1B) which dominate this sub-facies, commonly are partially destroyed by dolomitization, and can only be seen as hazy outlines within the texturally different interstitial material. Dolomitic mudstones are also found in this sub-facies, consisting of dolomitized aragonite.

Most of the thin sections contain minor amounts of scattered silt and occasional animal burrows.

Interpretation. This facies formed in a quiet, shallow water environment, mostly undisturbed by wave agitation which might otherwise destroy the pellets. A limited population of animals inhabited the quiet bottom waters, contributing abundant pellets to the sediment, which was occasionally reworked by burrowing fauna. Dolomitization was possibly penecontemporaneous at or near the depositional interface as Mg-rich bottom waters altered newly formed aragonite muds or fecal pellets. The dolomitic pellets could also be derived from reworking of previously dolomitized sediments by the local animals. The ubiquitous scattered silt grains were probably carried by winds blowing off the positive area to the east, and dropped over the shallow basin.

Intraclast-oolith sub-facies

Description. The most common rock type in this sub-facies is a bio-fragmental, oolith, intraclast dolomitic packstone. Phosphatic fossil fragments are similar to those found in the mud-pellet sub-facies while other fossils have been entirely replaced with sparry calcite or leached to form porosity. These rocks contain abundant dolomite intraclasts (photo-plate 2A) with the more shoreward part of the facies containing occasionally abundant ooliths with silt nuclei (photo-plate 2B). This sub-facies is characteristically very porous.

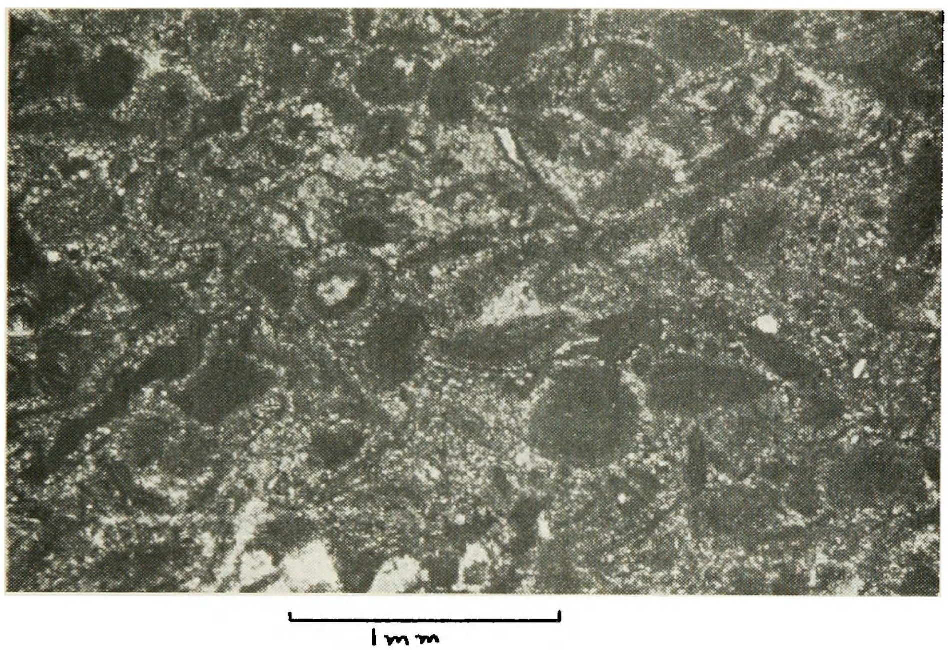
Interpretation. This sub-facies differs from the mud-pellet sub-facies primarily in the amount of bottom agitation. Storm waves would tear up the bottom sediments where the wave energy was expended and redeposit them as intraclastic debris. Ooliths would develop in shallow water where the bottom sediments receive constant wave agitation, as found in areas of shoaling. This sub-facies occurs shoreward of the mud-pellet sub-facies.

Sponge Spicule Facies

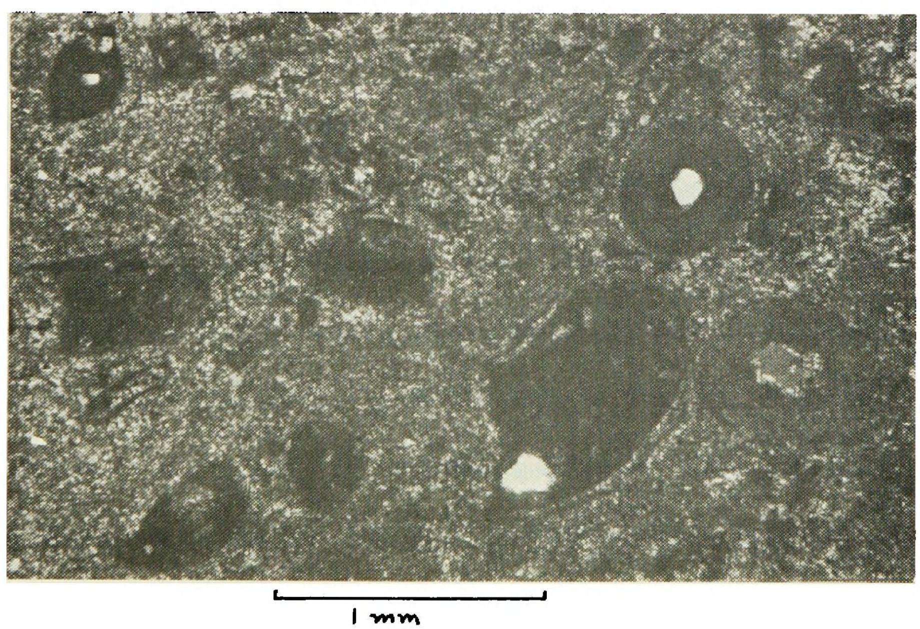
Description. This facies ranges from a dolomitic, sponge spicule packstone to a pelletal spicule wackestone, to a massive spicular chert. In the upper parts of the Franson interval, chert intertongues with the lower Shedhorn Member.

Interpretation. Sponges normally inhabit a quiet, non-shifting bottom environment (Cressman and Swanson, 1964). Sponge spicules accumulated in aragonite muds, sometimes to the extent of forming beds of chert. This facies can be used for correlation in the eastern sections when it forms as a thin unit. The chert which intertongues with the upper sands probably represents quiet water adjacent to where sands were being reworked.

PHOTO-PLATE 2



A. CCp-9L: Intraclast-Oolith Sub-Facies; intraclast-oolith packstone.



B. SR-5M$_1$: Intraclast-Oolith Sub-Facies; ooliths with silt nuclei.

Depositional Environments and Lateral Relationships

Fig. 7 represents a hypothetical environment of deposition in the eastern province during a transgressive phase. The different facies migrated generally east and west across the area with changes in sea level, resulting in the intertonguing relationships found on the stratigraphic cross-section in Fig. 8. The eastern sand facies, represented by the lower Shedhorn Member, was deposited in a beach and longshore bar environment (Shepherd, 1971). The stromatolitic (?), silty laminated facies formed seaward of the sand facies where deposition was influenced by intermittent influx of fine clastics and filamentous algae growth, suggesting an intertidal zone. Basinward, the intraclast-oolith sub-facies probably formed within an agitated zone influenced by effective wave-base and areas of shoaling where wave energy was dissipated. Accretionary layers of calcium carbonate coated the silt and intraclastic grains where constant wave agitation rolled them about on the bottom. The silty laminated facies lay shoreward of these protecting shoals, receiving occasional influxes of fine clastics during storms or incoming tides. Periodic storms tore up the bottom sediments which were then distributed as intraclastic debris. In slightly deeper parts of the shallow basin, below effective wave-base, deposition was dominated by precipitation of aragonite muds and organic pellets. Prolific sponge growth was associated with rather unagitated sediments of aragonite muds and some pellets. The thin sponge spicule facies was used as correlation for most of the eastern province, as can be seen in Fig. 8.

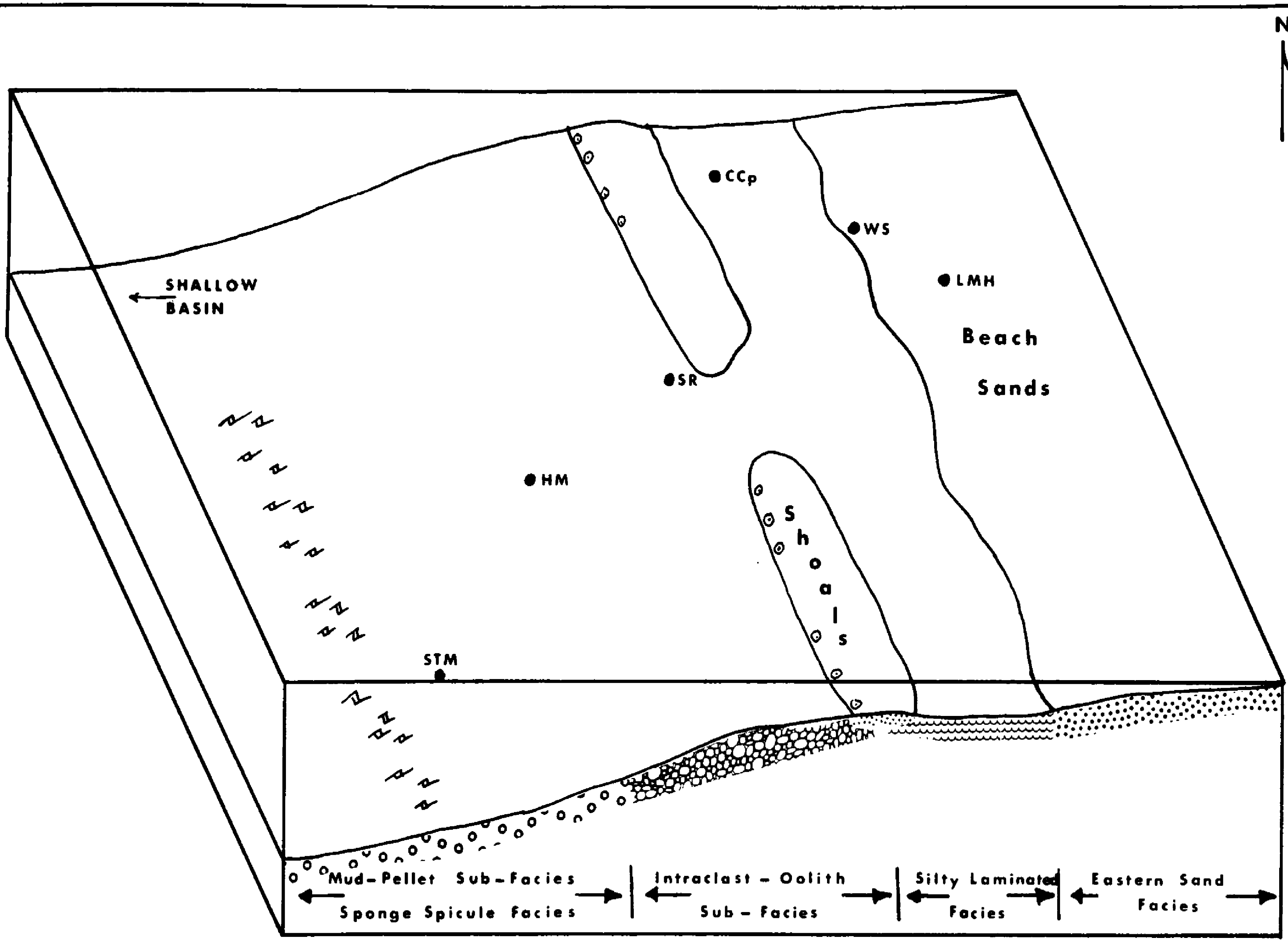


Fig. 7 - Eastern province: depositional environments.

Horizontal Scale 0 5 10 Miles

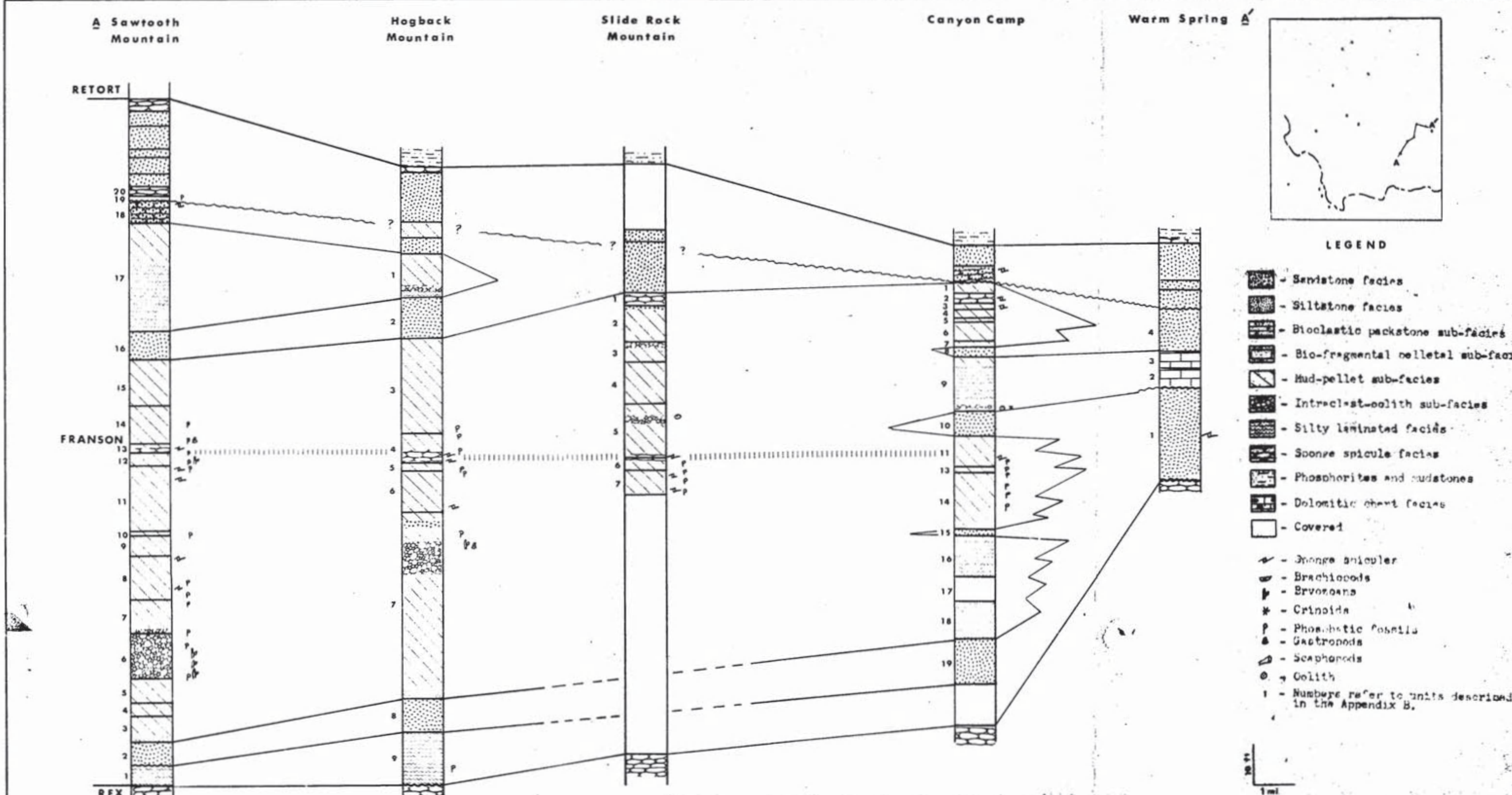


Fig. 8 - Stratigraphic cross-section across the eastern province.

Western Province

In the western province, the following four facies have been identified: the western sand facies, the bioclastic limestone-dolomite facies, the siltstone facies, and the dolomitic chert facies. All four facies intertongue at sections in the Tendoy Mountains, where the shelf-edge bioclastic carbonates are best developed; while the siltstone and dolomitic chert facies favored the more protected conditions within the shallow basin to the east, as seen at the Daly's Spur and Sheep Creek sections.

Western Sandstone Facies

The greatest influence of this facies was during early Franson deposition when the sands covered most of the western province and formed the most basal unit of the Franson. The sands are most prominent at the Big Sheep Creek and Little Water Canyon sections in the Tendoy Mountains, where sandstone deposition continued into the middle of the Franson interval.

Description. This facies outcrops as a gray to gray-brown sandstone, containing scattered fossil fragments and a few "boilerpipe concretions." Clastic material characteristic of this facies are abundant quartz grains (60-90%), chert grains (5-20%), and phosphatic grains (5-30%). The sand consists of sub-rounded to rounded grains of fair-to good sorting varying between 0.1 to 0.4 mm. in size, with decreasing grain size to the southeast. Fine-grained carbonate commonly forms the matrix, while the only fossils observed were some brachiopods and phosphatic crinoids.

Interpretation. This sandstone facies blankets the western province during early, and to a much lesser extent, late Franson deposition during periods of maximum regression. At the Big Sheep Canyon and Little Water Canyon sections, sandstone deposition continued into middle Franson as longshore bar deposits which were laterlly adjacent to the shelf-edge bioclastic carbonate buildups with which they intertongue. Sub-aerially exposed Pennsylvanian quartz sand, Meade Peak phosphate, and Rex chert beds to the north or northwest, probably were the source of the clastic material, which were eroded, and then reworked and spread by shallow water wave and current action over the underlying cherts of the Rex Member.

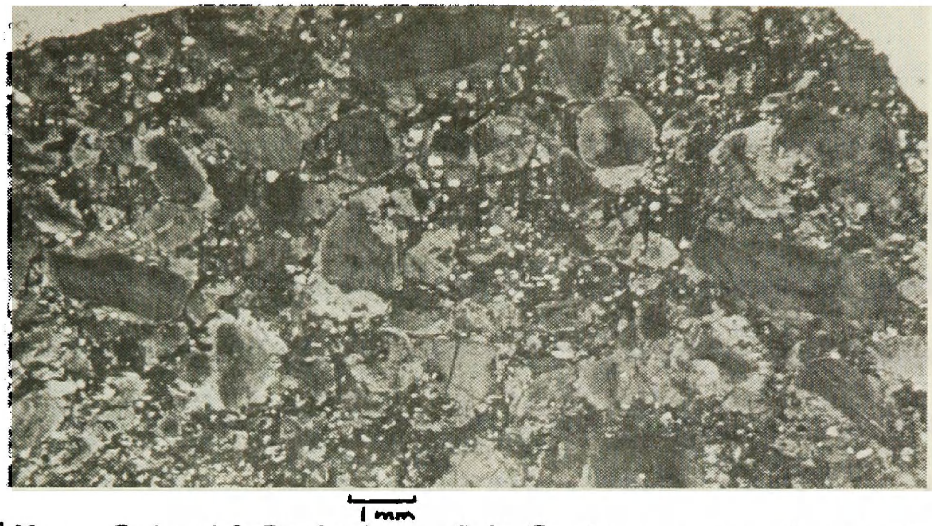
Bioclastic Limestone-Dolomite Facies

This bioclastic facies comprises the characteristic units of the shelf-edge carbonate bank and is divided into two sub-facies: the bryozoan, brachiopod, crinoid packstone sub-facies and the biofragmental pelletal wackestone sub-facies.

Bryozoan, brachiopod, crinoid packstone sub-facies

Description. This sub-facies is characterized by dense populations of ramose bryozoans, productid and spirifer brachiopods, and crinoid fragments. (photo-plate 3A, 3B, 3C) The most common fossil associations are bryozoans and brachiopods or bryozoans and crinoids, although all three are sometimes found together. Medium-grained sand is scattered among the fossils, which are often partially silicified or dolomitized. Siliceous sponge spicules are present as are dolomite

PHOTO-PLATE 3



A. BSC-24M_2: Crinoid Packstone Sub-Facies; note abundant sand grains.

B. LSC-8U: Bryozoan Packstone Sub-Facies: fossils are silicified.

C. LW-9M_5: Brachiopod Packstone Sub-Facies; productid brachiopods, partially silicified.

rhombs.

Interpretation. Franson-equivalent bioherms in southeastern Idaho were described by Brittenham (1972) and contained identical fauna to those found in the bioclastic facies in southwestern Montana. The bioherms and bioclastic facies both occupy similar positions relative to the shelf-edge which suggests comparable depositional environments. Although the bioclastic facies does not thicken locally as the bioherms do, lateral control is insufficient to outline the geometry of the unit.

This sub-facies favored well-circulated and aerated waters conducive to rapid organic growth and carbonate deposition. Biologic growth was possibly controlled by a bathymetric high or shoal, such as a longshore bar deposited prior to the organic buildup, where the biota would thrive in a zone of circulating water. The active hinge line of Cressman and Swanson (1964), which approximates the position of the Beaverhead Arch, could be the basic influence for the development of this bathymetric high (J. A. Peterson, personal communication 1972). The thick section at Big Sheep Canyon may represent a bioclastic buildup which kept pace with rising sea level, while adjacent sections contained the deeper, quiet water siltstone facies.

The intertonguing of the bioclastic facies with the longshore sands suggests the possibility that the bioclastic rocks seen at the measured sections in the Tendoy Mountains may represent only the edge of a large bioherm, such as those described by Brittenham (1972).

Evidence for shallow, circulating waters on a bathymetric high include:

1. Characteristic biota of this sub-facies favors this type of environment for rapid growth.
2. It is found interbedded with coarse-grained longshore sands which would probably form under similar conditions of moderate-to-strong current activity.
3. This sub-facies is present in the uppermost Franson during a shallow water regressive stage.

Bio-fragmental pelletal wackestone to packstone sub-facies

This sub-facies represents the first carbonate unit above the basal sandstone at the Cedar Creek, Little Water Canyon, and Big Sheep Canyon sections, and is not found higher at the latter two.

Description. Identifiable fossil fragments in this sub-facies include crinoids, pelecypods, gastropods, scaphopods, and algal-blades within a pelletal matrix. The original aragonitic mud matrix has been dolomitized, but has remained fine-grained. Quartz silt grains are widely scattered, and some samples appear to be burrowed. Crinoid fragments are phosphatized and commonly leached, providing good porosity. *Plagioglypta* scaphopods and Belleraophontacean gastropods occur in this facies at Cedar Creek, as are abundant micro-gastropods identified by Welch (1972).

Interpretation. The fauna and sediments found in this sub-facies probably formed in a somewhat restricted, protected environment, where the gastropods, scaphopods, and pelecypods lived among the algal-blades. Little agitation affected this sub-facies either from waves or burrowing animals, as fecal pellets accumulated among the algae.

Yochelson (1968), suggested that the _Plagioglypta_ and Belleraophontaceans indicated shallow water, possibly hypersaline, conditions.

Siltstone Facies

The siltstone facies occurs at Little Sheep Creek, Big Sheep Canyon, Little Water Canyon, Daly's Spur, and Sheep Creek sections, where it lays below the resistant dolomitic chert facies.

Description. In outcrop, this facies is thin-bedded with occasional wavy laminae or it is recessive and covered. It consists of well-sorted, rounded silt to fine sand grains (0.04 - 0.08 mm.) within a dolomitic matrix. The dolomite is commonly found in the form of rhombs and overgrowths. Fossil fragments are scarce, usually consisting of some sponge spicules and an occasional crinoid fragment.

Interpretation. This facies was probably a lateral equivalent of the longshore bar facies, forming on the fringes of the main current, where only silt size grains were transported and deposited. This unit overlies coarser grained sandstones and bioclastic limestones, which probably represent a transgressive phase. The occurrence of sponge spicules suggests that in slightly deeper water, adjacent to where clastic silt is being moved about by currents, prolific sponge growth took place. This is further substantiated by the intermixing of silt and chert.

Dolomitic Chert Facies

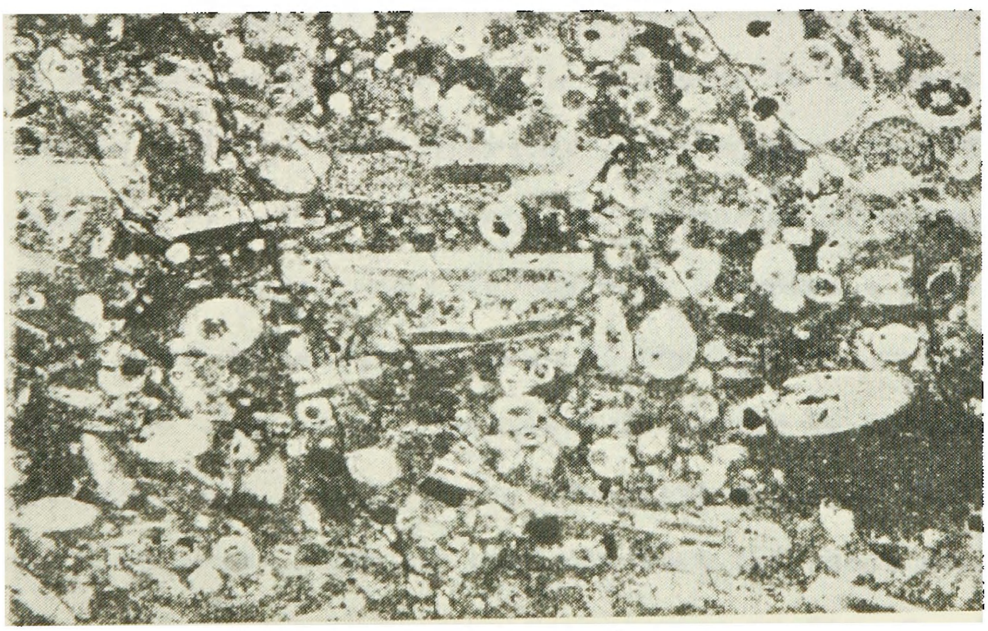
This facies makes up the bulk of the sediments in the upper part of the middle Franson across all of the western province.

Description. These rocks are the most easily distinguishable part of the Franson in outcrop, usually overlying a semi-covered interval of the siltstone facies, and forming a massive resistant cliff comprised of interbedded and intermixed dolomite, silt and chert. Chert occurs in layers, lenses, nodules, irregular masses, and boutinage-like structures; while the silt (0.03 - 0.08 mm.) usually forms thin beds or is found as scattered grains in the more massive chert and dolomite. The carbonate portion of this facies, in thin section, consists of mostly dolomite rhombs and overgrowths, with some rhombs up to 0.1 mm. in diameter (photo-plate 4A). Chert is present in nearly all thin sections to some extent, from dominant to interstitial nodules and secondary crevass fillings. Although much of it forms a microcrystalline mosaic, sponge spicules or their shadowy outlines make up a considerable portion of the siliceous fraction. Except for the sponge spicules, fossils are scarce, although a few scattered crinoid and brachiopod fragments are found.

Interpretation. The most widespread occurrence of this facies came during a period of maximum transgression in middle-to-late Franson. Quiet water deposition was dominated by aragonite mud and sponge spicules with an occasional scattering of windblown(?) silt. Siliceous sponges probably thrived in this quiet, deeper water, contributing abundant spicules to the sediment. Although all the chert doesn't show mass

PHOTO-PLATE 4

A. LW-8U: Dolomitic Chert Facies; larger dolomite rhombs are up to 0.11 mm, in a chert matrix; note overgrowth in the center.



1 mm

B. SR-1L: Abundant sponge spicules, common in both the sponge spicule facies and the dolomitic chert facies.

siliceous spicules, many of the spicules observed were in a state of partial dissolution, or replaced by secondary chalcedony, with barely discernible outlines. This implies that many of the spicules were probably dissolved and reprecipitated as microcrystalline chert, destroying any record of their existence.

Depositional Environments and Lateral Relationships

Fig. 9 represents depositional environments and their spatial distribution in the western province during periods of maximum longshore bar and bioclastic carbonate development. A diverse biota thrived on the well-aerated, circulating waters associated with a topographic high on the shelf-edge. Ramose bryozoans, spirifer and productid brachiopods, and crinoids were probably distributed across an energy zone like similar faunas described in bioherms in southeastern Idaho by Brittenham (1972): where spirifer brachiopods occupied the highest energy zone, while ramose bryozoans and productid brachiopods thrived in a less agitated zone, and crinoids also occupied a more protected area. Sands were deposited adjacent to the bioclastic carbonates, distributed from a north or northwesterly source by longshore currents. The geographic distribution of the longshore sands in relation to the bioclastic carbonates seems to indicate that the sands were laterally east of the carbonate buildup, as represented in Fig. 9. Paleo-wind directions during the Permian were apparently from the northeast, which could feasibly drive longshore currents down the eastern edge of the carbonate banks. However, the sands could just as well occupy the

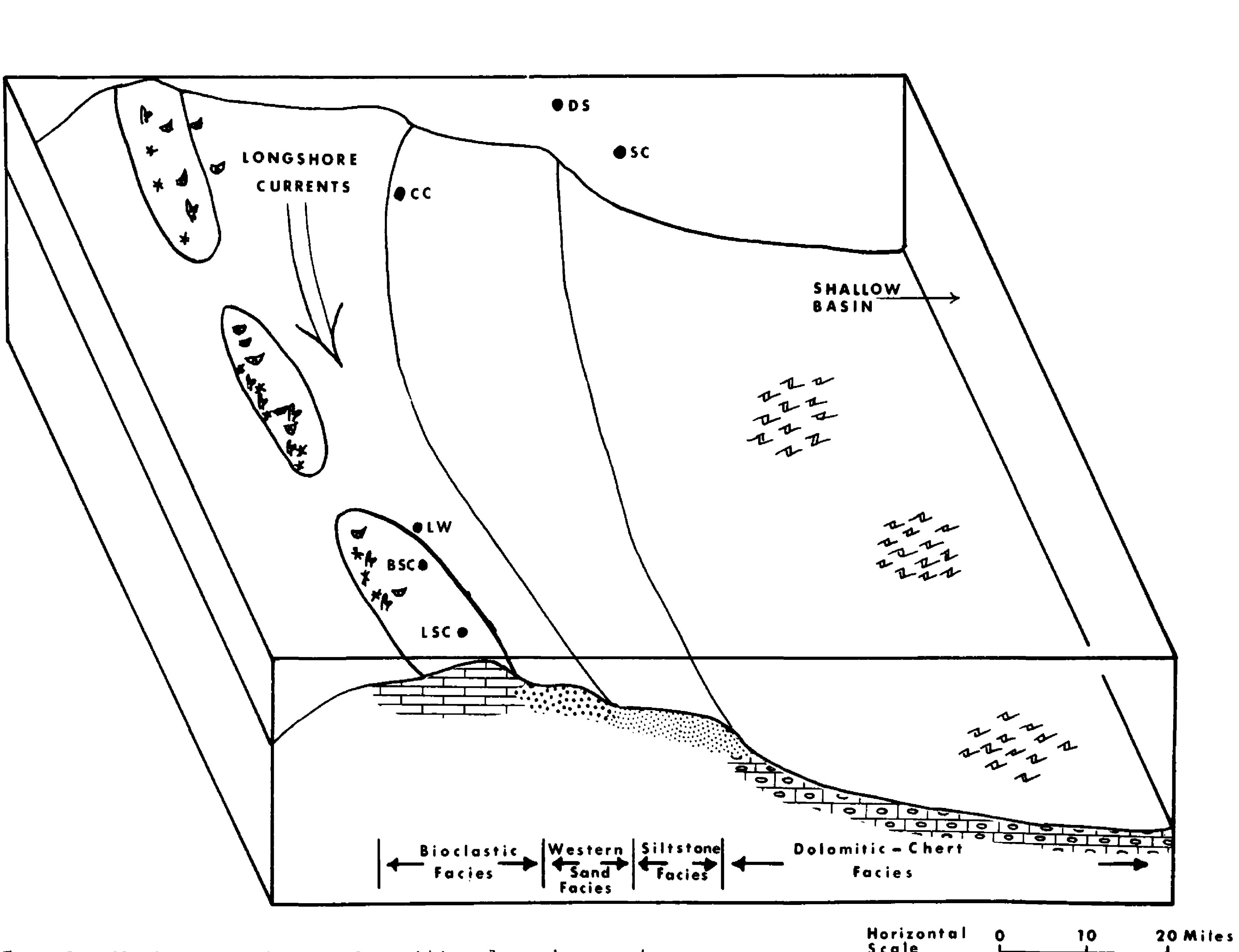


Fig. 9 - Western province: depositional environments.

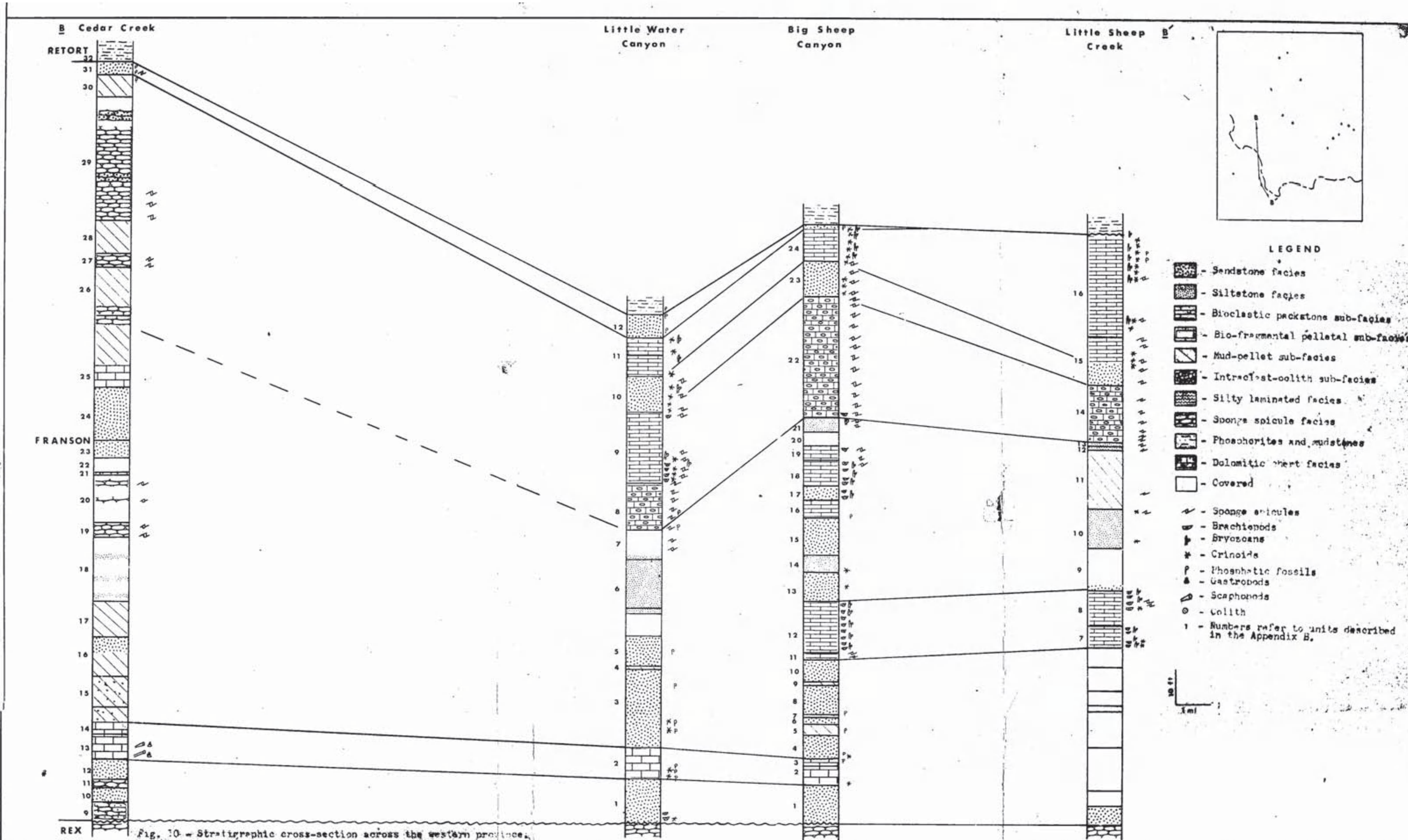


Fig. 10 - Stratigraphic cross-section across the western province.

opposite position on the west side of the bank, with longshore currents being derived from swells coming in off the open ocean to the west. A conclusive answer cannot be obtained without more control points of better distribution from which the geometry of the carbonate and sands can be determined.

The sandstones graded laterally into siltstones which were distributed along the edge of the main longshore currents. Silty pelletal mudstones were deposited in the more basinward areas to the east where the bottom waters were rather undisturbed. Prolific sponge growth thrived in this environment, especially during middle-to-late Franson deposition, creating a siliceous sponge spicule ooze on the bottom (photo-plate 4B). These facies intertongued with each other as changes in water depth altered the local environments.

Phases of Franson Deposition

For the purpose of demonstrating lateral facies relationships, the Franson Member was divided into three main phases of deposition within a complete transgressive/regressive cycle: phase A which consists of the lower one fourth, phase B the middle half, and phase C the upper one fourth of the total Franson interval. Since evidence for absolute time lines, such as key beds, or faunal occurrences, were not found for the whole area, division of the Franson was based on lithological criteria. The uniform pattern of stratigraphic thickness of the Franson Member over most of the study area lends some validity to the use of thickness for division of the unit. The amount of deposition was probably most uniform during the lower and upper quarters of the interval, as sandstone deposition dominates much of the area, while the greatest discrepancy of depositional thickness probably occurs within the middle half during the period of maximum transgression and carbonate buildup. Since general accuracy and not absolute accuracy is the design of the divisions, the method used seems quite valid.

Phase A

Lateral facies distribution during Phase A deposition is represented in Fig. 11. In the western and southwestern sections of the study area, a blanket of coarse basal sand comprised of phosphatic, chert and quartz grains was deposited upon the undulating surface of the Rex chert. The undulating and intermixed boundary between the chert and sands at the Big Sheep Canyon, Little Water Canyon and Cedar Creek sections suggests that the beginning of Phase A deposition in the western province follows a period of maximum regression or comes during the waning stages of regression. Quiet water carbonate deposition of the bio-fragmental pellet facies followed with continued transgression.

In the eastern province, late regression and early transgression initially laid down over the Rex chert, silty laminated, intraclastic, dolomites, which were followed by a regressive tongue of Shedhorn sandstone. The onset of the main transgressive phase covered the sandstone tongue with intraclastic and pelletal dolomites.

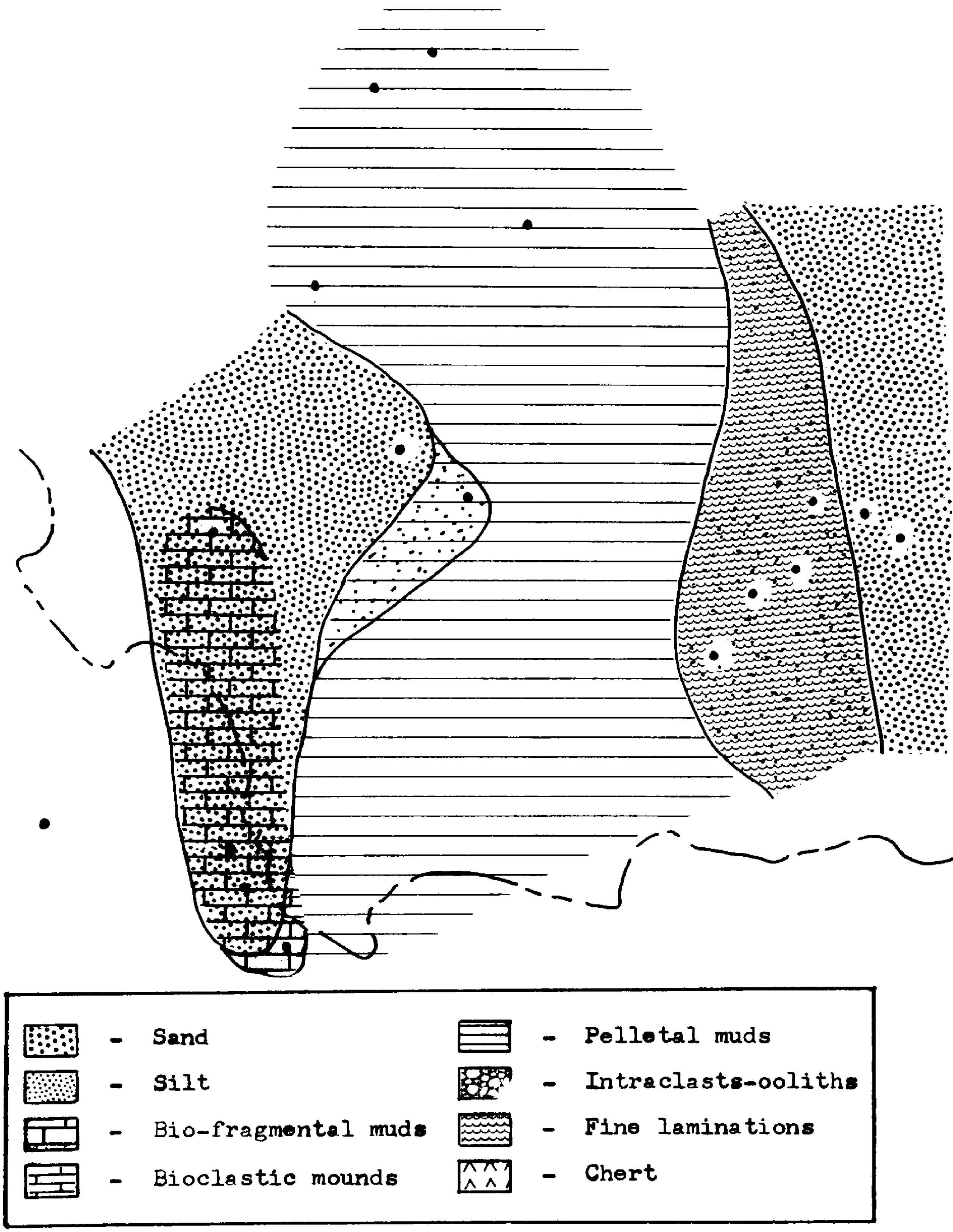


Fig. 11 - Facies distribution during Phase A.

Phase B

The main transgressive pulse occurred during Phase B and is represented by Fig. 12, which shows facies distribution during early Phase B deposition, and Fig. 13, which represents late Phase B deposition. Maximum carbonate accumulation occurred during this phase and maximum transgression in late Phase B is represented by the farthest eastward extension of carbonate as seen at Indian Creek.

In the eastern province, the southernmost sections in the Snowcrest Range received abundant intraclastic carbonate sediments during early Phase B which were replaced by pelletal-mud deposition late in Phase B. At the Canyon Camp section, intertidal deposition of scoured, silty laminated dolomites in early Phase B gave way to more intraclastic and oolitic sediments with continued transgression during late Phase B. Clastics shedding off the low-lying central Montana land mass continued, but influenced only the easternmost sections.

In southwesternmost Montana, early Phase B was dominated by bioclastic carbonate and longshore sand deposits. Lateral equivalents in the shallow basin included siltstones and dolomitic pelletal mudstones found at Daly's Spur and Sheep Creek. Further transgression in late Phase B resulted in the deeper water dolomitic chert and siltstone facies overlying the bioclastic carbonates and longshore sands. The northern and central sections received silty, pelletal sediments in the middle of the basin.

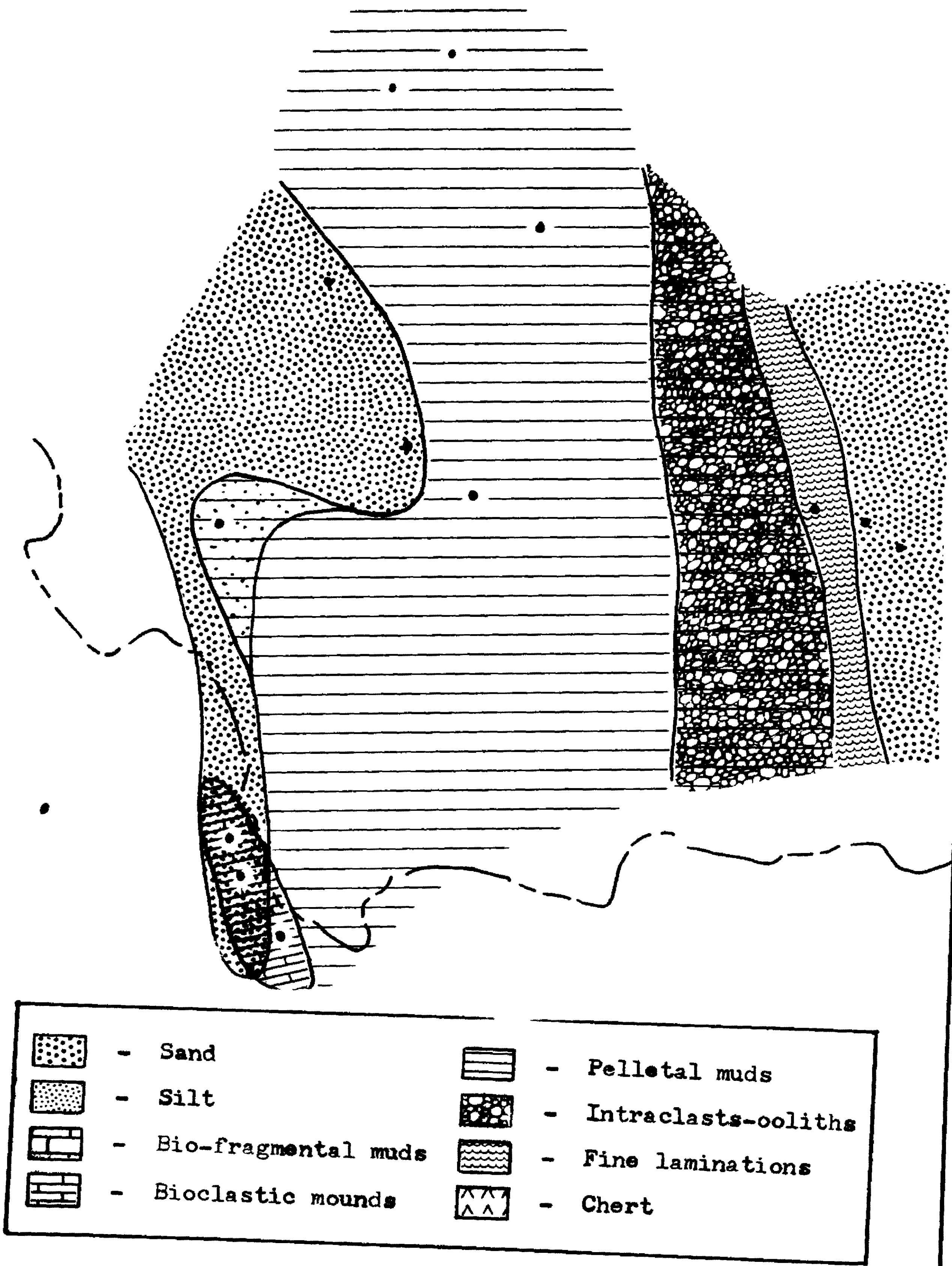


Fig. 12 - Facies distribution during early Phase B.

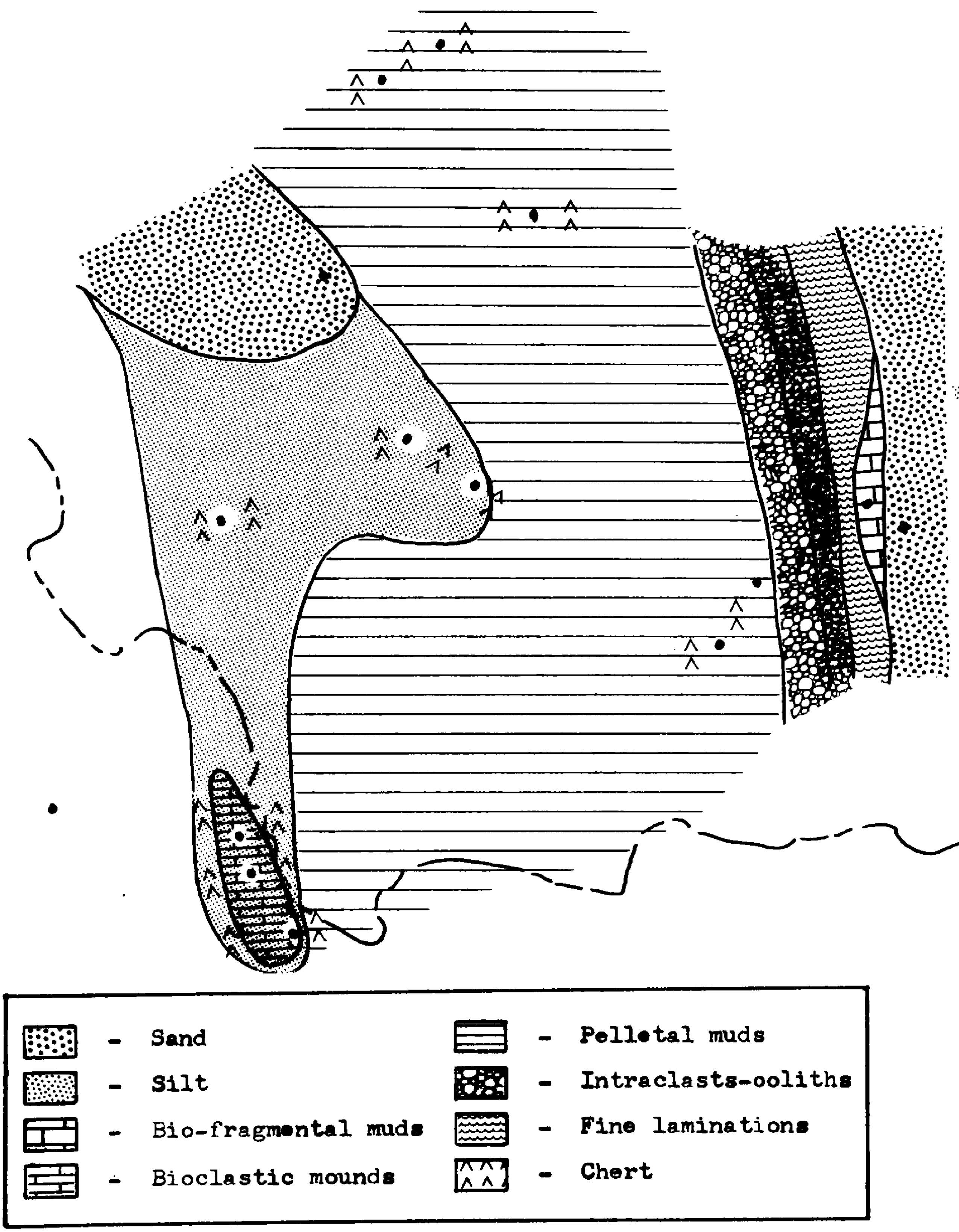


Fig. 13 - Facies distribution during late Phase B.

Phase C

During Phase C (Fig. 14) deposition of sandstone was prevalent as a general regression, with accompanying sand influx, occurred across the study area.

In the eastern sections, the initial signal of Phase C regression was a tongue of lower Shedhorn sandstone, which blanketed the underlying carbonates, as the strand line moved basinward. A period of recovery followed, resulting in an eastward-extending tongue of carbonates, as the seas moved back in. Final regression distributed a cap of lower Shedhorn sandstone, and spicular chert beds, at the top of the Franson as far west as the North Big Hole Canyon, Sheep Creek, and Daly's Spur sections (Fig. 14).

The western and southwestern areas followed a similar sequence, with the initial phase of regression spreading a thin blanket of sand over the area, followed by a period of recovery as silty carbonate deposition took place. This was followed by the final phase of regression, in which the shelf-edge province received increasing amounts of clastic material, but was again dominated by bioclastic carbonate sediments. Influence by the northwestern clastic source was drastically reduced during Phase C.

Maximum regression occurred during Phase C deposition, prior to deposition of the Retort phosphates. Evidence includes:

1. Blanket sand from the east spreading over most of the area, especially in the central and eastern parts.

2. Conglomeratic pebble beds overlying erosional surfaces in the upper sands.

3. Erosional surface between the uppermost Franson and overlying Retort phosphates at Little Sheep Creek. Lowermost Retort is usually coarse-grained.

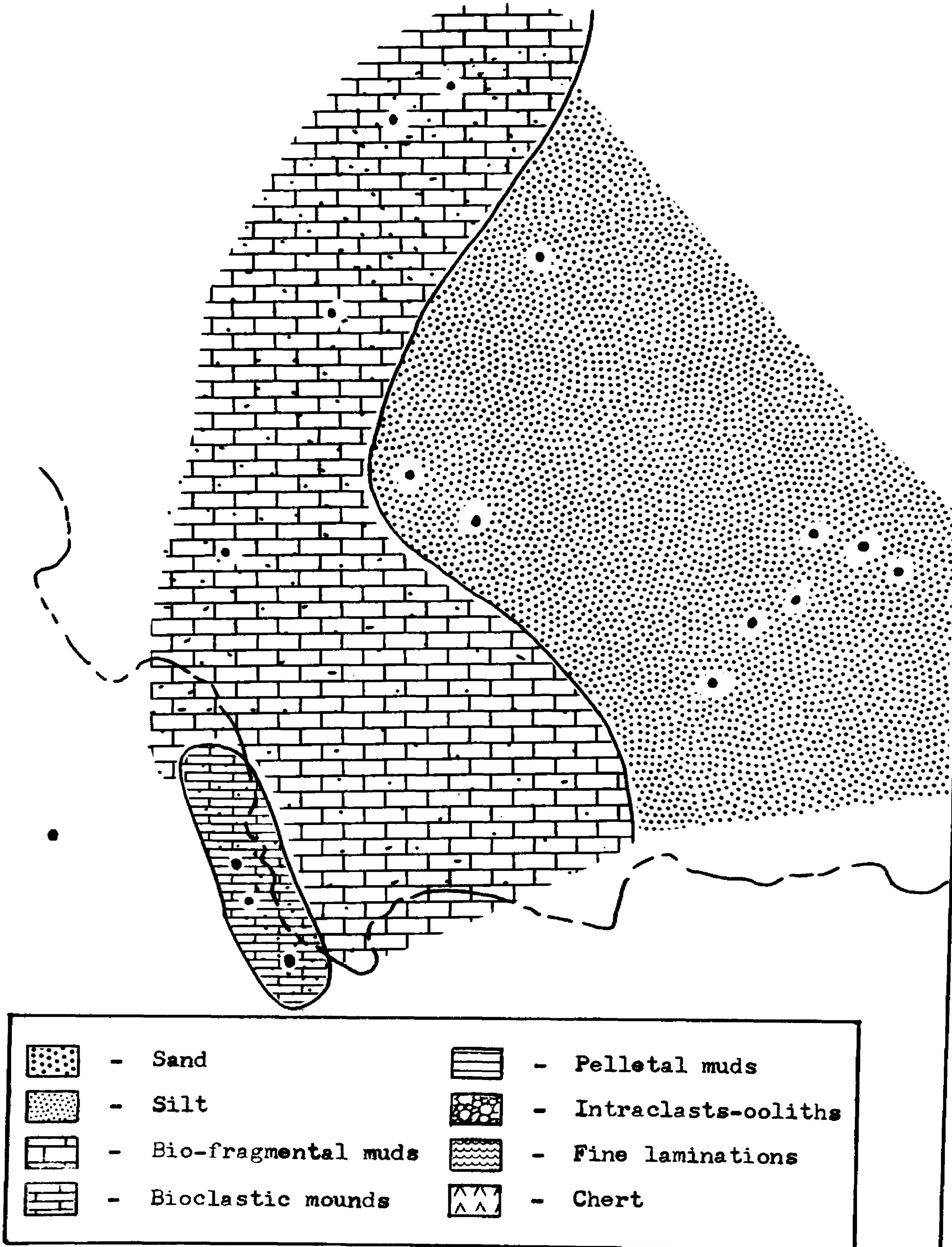


Fig. 14 - Facies distribution during Phase C.

ALTERATION

Silicification

Chert is common in the Franson member and throughout the rest of the Phosphoria Formation, and forms as beds, lenses, nodules, irregular masses, matrix and replacement of shell fragments. It most commonly occurs as microcrystalline quartz or siliceous sponge spicules, but also is found as secondary chalcedony and doubly-terminated quartz crystals.

Source of Silica

Normal sea water contains very low concentrations of silica of about 1 to 2 ppm. (Krauskopf, 1959), so to account for the abundant occurrences of chert in the Phosphoria, excess silica must be introduced. Sources of this extra silica could come from vulcanism and weathering of a land mass.

Near Orofino, Idaho, to the west, lie Phosphoria-equivalent rocks of the Casto Volcanics (Scholten, 1957), where extensive vulcanism could have contributed great amounts of silica to the sea water from underwater lava flows and the associated escaping gases and vapors. Extra silica could also be derived from intermittent rivers draining the land mass to the east and northeast. Red beds and evaporites in Permian rocks in eastern Wyoming suggest a hot, dry climate, creating alkaline conditions in which excess silica could be taken into solution by surface waters. Intermittent rivers draining this land mass and travelling across the silica-rich sands of the exposed Quadrant Formation could introduce large amounts of silica to the Franson sea.

Formation of Silica

Silica can be removed from solution by organic and inorganic means. Organisms such as siliceous sponges, diatoms, and radiolarians build their skeletons from dissolved silica, which are later added to the sediments when they die. Siliceous sponge spicules are abundant in the Franson Member sediments. Some thin sections are composed entirely of spicules, while in others the spicules form the matrix. However, much of the chert is microcrystalline and identification of spicules is difficult. The percentage of chert deriving its source of silica from sponge spicules can only be inferred, as spicules are found in all stages of dissolutions, and diagenesis probably contributed heavily to the destruction of the original volume of the spicules. Inorganic, direct precipitation of dissolved silica from sea water requires the presence of electrolytes and suspended particles and the process involves "...absorption of soluble silica on suspended matter as it comes in contact with electrolytes." (Bien, et al, 1959). Permian sediments contain ample suspended material, and electrolytes are supplied by normal marine water, therefore with excess silica available in the sea water, inorganic precipitation could contribute substantially to the silica found in the sediments.

Sponge spicules account for many of the forms of chert found in the Franson Member, as some of the chert beds and lenses appear to be made entirely of sponge spicules. The thick dolomitic chert facies in the western province appears to have formed from the vast accumulation of siliceous sponge spicules in quiet, deeper water. Thin sections show abundant spicules as ghostly outlines, often having been partially destroyed by diagenesis, however some of the arrangements of the spicules suggest original sponge structure.

Much of the massive and interstitial chert cannot be directly attributed to spicules and may occur as direct silica precipitation from sea water or diagenetic replacement.

Secondary replacement, in the form of chalcedony, is common. This silica may be found as matrix, fossil replacement, void fillings and calcite replacement. Silica dissolves at a pH greater than 9, and precipitates from solution at a pH less than 9, while calcite responds in the opposite direction. The pH of bottom sediments could vary widely and as decaying organisms lowered the local pH, silica could easily be dissolved at one locality and reprecipitated at another (Pittman, 1959). Local variations might be reflected by selective replacement of fossils or matrix, as seen in many thin sections.

Dolomitization

Nearly all carbonate rocks of the Franson Member have been dolomitized. The dolomite is found as several different forms ranging from minute microcrystalline grains, to a mosaic of small rhombs, and finally to larger, well-developed rhombs up to 0.11 mm. in diameter. Each dolomite type is associated with certain rock types.

Primary dolomite is exceedingly rare in Recent depositional environments to account for the abundance of dolomite in the geologic record. Most theories on dolomite formation require increasing magnesium concentration in brines which replaces some of the calcium in the calcite structure to form the dolomite. Several theories can be applied to the dolomites of the Franson Member.

Penecontemporaneous dolomitization requires restricted circulation where aragonite and gypsum precipitation may take place. This precipitation results in an increase in the Mg/Ca ratio of the sea water, and a Mg-rich brine would then occupy the bottom waters, as its density is greater than that of normal sea water. In such an environment, precipitating aragonite needles would be dolomitized as they sank to the bottom through the Mg-rich brines (Friedman and Sanders, 1967).

Minute, microcrystalline dolomite grains are associated with the deep water mudstones, and probably are derived from dolomitization of aragonite needles as they settle to the bottom. This method may also occur within the intraclast-pelletal facies. However, much of the dolomite forms a mosaic of small interstitial rhombs between pellets, and intraclasts, suggesting diagenesis of high-Mg aragonite muds near the depositional interface. Enrichment of Mg, by dissolving low-Mg calcite from the aragonite, could result in the formation of dolomite (Winston, personal communication 1972).

In the "seepage reflux" theory of Adams and Rhodes (1960), Mg-rich brines were produced in restricted waters behind organic reefs and barriers. Evaporation of the restricted waters increased the salinity, causing heavy hypersaline brines to sink to the bottom which then slowly replaced connate waters in the permeable carbonate sediments. As these heavier waters migrated down slope through the sediments, Mg in the brines replaced part of the calcium in aragonite and high-Mg calcites, to form the dolomite.

Large, euhedral dolomite rhombs are prevalent in many parts of the sections containing bioclastic buildups, in the southwestern portions of the study area. This would indicate optimum conditions for growth of dolomite rhombs which might be explained by the "seepage reflux" method of dolomitization. Mg-rich solutions passing through the sediment could provide a continuing supply of magnesium from which large crystals might grow. The apparent organic carbonate buildup could provide the necessary restricted environment to produce the brines. Mg-rich connate waters trapped in the sediment could also provide continuing dolomite growth well below the depositional interface.

Fine-grained dolomites found in the intertidal facies in the eastern province, might be explained by Mg-enrichment of near surface interstitial waters from evaporation during periods of sub-aerial exposure. These enriched waters would then dolomitize sediments which they passed through. This theory was suggested for dolomites now forming on "sebkhas" in the Persian Gulf.

Phosphatization

Fossil fragments have been selectively replaced by phosphate, pellets have been altered, and some fossils are filled in with phosphatic muds. Identifiable phosphatized fossils include many crinoid fragments; plus pelecypod, gastropod, foram, and ostracod fragments. Forams, gastropods and other chambered animals have been filled in with a phosphatic microcrystalline matrix.

Cool, upwelling waters from the deeper basin to the west could supply the necessary enrichment for phosphate development. Krauskopf (1959) notes that one way apatite may form is "...by replacement of calcium carbonate by reaction with dissolved phosphate." This reaction would explain the occurrence of phosphatic fossil fragments within a dolomitic matrix which has not been phosphatized. Cole (1970), suggested that void or chamber fillings of phosphate material might be attributed to "...micro-environments set up within the voids or organisms, perhaps by decaying organic matter." Such localized environments could account for the phosphatic alteration of the infilled organisms and pellets.

PERMIAN PALEOENVIRONMENTS

Wyoming and Montana were influenced by a hot, dry climate during Permian time, as suggested by deposition of red beds and evaporites in eastern Wyoming, and eolian deposits in central Montana. The hot, dry alkaline climate may have influenced increased solution of silica to be carried by intermittent streams to the Franson sea, promoting excess siliceous sponge growth. The hot climate would also promote carbonate deposition as cool, upwelling waters were warmed up in the shallow basin. During the Permian, the equator was thought to have passed through central Wyoming, therefore paleo-winds would be blowing off-shore from the northeast. These winds may have influenced depositional environments by driving waves into the shelf-edge bioclastic facies, increasing their growth and carrying longshore sands along the eastern edge of the bioclastic buildups. However, off-shore swells may have been an overriding influence in the development of the bioclastic bank and longshore sand environments, reversing the lateral relationships of the two facies.

In southwestern Montana, carbonate deposition occurred across a shallow basin with bioclastic carbonates dominant in the southwest along a shelf-edge; sponges and pelletal mudstones most prominent in the central part of the basin; and pelletal, intraclastic, oolitic, and laminated sediments along the eastern shoreward parts of the basin. Clastic material was derived from the east and northeast, and the northwest.

TRANSGRESSION - REGRESSION IN THE FRANSON MEMBER

The following is an outline of transgressive and regressive phases of deposition during Franson time, with evidence seen in the study area.

1) Continued regression at the beginning of Franson deposition (Phase A):
   a) Lower Shedhorn tongue in the east.
   b) Lowermost western sandstone tongue in the western province.
2) Transgressive phase, with minor fluctuations (early Phase B):
   a) Eastern: interbedded pelletal-intraclastic facies.
   b) Southwestern: sand source still quite prominent, but with transgressive interbeds of fossiliferous carbonate, becoming more abundant higher in the section.
3) Slight regression: middle Franson.
   a) Eastern sections become siltier and at Canyon Camp there is a tongue of sandstone.
   b) Western: the Cedar Creek and Kelly Gulch sections contain a middle sandstone tongue; and a bioclastic unit at the Big Sheep Creek section contains a cap of conglomeratic intraclasts, suggestive of shoaling.

4) Continued transgression (late Phase B):

a) East: dominated by sponge spicule and pelletal deposition.

b) West: siltstone, mudstone, and spicular cherts deposited.

5) Initial regression (earliest Phase C): tongues of sandstone are found at nearly all sections.

6) Recovery transgression:

a) Carbonate again transgresses eastward.

b) Sand influence dwindles in the west.

7) Final regression:

a) Lower Shedhorn spread from the east to cover most of the area. Conglomerates and erosional surfaces are found within the upper sands.

b) Carbonate sections: show increase in sand content and shallow water environments.

SUMMARY OF CONCLUSIONS

The Franson interval was deposited within a complete transgressive/regressive cycle.

Sandstone dominated deposition during the regressive phases in early and late Franson deposition.

Sand was derived from two source areas which contributed identical clastic grains of chert, phosphate, and abundant quartz.

Bioclastic packstones of ramose bryozoans, productid and spirifer brachiopods, and crinoids, developed on the shelf-edge in the southwest part of the study area. This fauna is identical to that found in bioherms in southeastern Idaho by Brittenham (1972) which lie in the same shelf-edge trend, and suggests a similar carbonate buildup.

Longshore sands from a northwestern source were deposited adjacent to the bioclastic carbonate buildups.

Siltstone occupied areas on the edge of the main longshore currents in deeper water, where only fine silt grains are affected by the gentle currents.

The origin of most of the chert is attributed to the abundant siliceous sponge spicules associated with the dolomitic cherts. These sponges probably thrived in the quiet waters of the basin, and spread to all parts of the study area during maximum transgression in middle Franson time. Increased sponge growth may have been influenced by an increase in silica in the sea water by vulcanism or weathering of a land mass.

Dolomitic pelletal mudstones were deposited in the central parts of the shallow basin, below wave base.

Intraclastic and oolitic sediments were deposited shoreward from the pelletal sediments in shallower water where frequent agitation by waves tore up the bottom to form intraclasts, or constant wave agitation in areas of shoaling caused oolites to form.

Silty, laminated, and possibly stromatolitic sediments in the east suggest intertidal carbonate deposition influenced by intermittent influx of sand.

Deposition of the overlying Retort phosphates started during maximum regression or early transgression, as suggested by the abundant sand and shallow water sediments of latest Franson, the undulating or erosional contact, and the conglomeratic or coarse grain beds found in the lowermost Retort.

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APPENDIX A

The following is a list of surface sections used in making this report, and described in Appendix B.

1. Big Sheep Canyon
2. Canyon Camp
3. Canyon Creek #3
4. Cedar Creek
5. Daly's Spur
6. Hawley Creek
7. Hogback Mountain
8. Kelly Gulch
9. La Marche Gulch
10. Lazyman Hill
11. Little Sheep Creek
12. Little Water Canyon
13. North Big Hole Canyon
14. Sawtooth Mountain
15. Sheep Creek
16. Sliderock Mountain
17. Warm Springs

APPENDIX B

The following are descriptions of the sections in southwestern Montana used in making this report. Complete descriptions of the entire Phosphoria Formation were done by Cressman and Swanson (1964). The Franson Member exclusively, was measured, sampled and petrographically examined by the writer. The entire section up to the Retort Member was measured at the La Marche Gulch, Canyon Creek #3, North Big Hole Canyon, Cedar Creek, and Hawley Creek sections. This part of the section had not been measured before at Cedar Creek. Data include field notes and petrographic description of thin sections. More detailed location directions can be found in Cressman and Swanson (1964).

Big Sheep Canyon, SE¼ SW¼ sec. 35, T. 14 S., R. 10 W., measured and sampled by the writer in July 1971.

Unit	Thickness	Description
Retort Member	---	Phosphorites and mudstones; lowermost is phosphatic sandstone.
Franson Member		
BSC-24	11 ft.	Packstone: ramose bryozoans, crinoid fragments; minor quartz grains and phosphate grains.
BSC-23	10 ft.	Sandstone: some phosphatic grains, abundant sponge spicules, calcareous.

BSC-22	34.5 ft.	Chert and dolomite: sponge spicules are conspicuous throughout; silty; chert dominates the upper 10 ft. Dolomite forms large rhombs often within a siliceous matrix. Cliff forming unit, with the appearance of chert and dolomite intermixed.
BSC-21	7.5 ft.	Siltstone: dolomitic; ramose bryozoans, brachippods; partly silicified.
BSC-20	4 ft.	Covered.
BSC-19	4.2 ft.	Wackestone: brachiopods, sponge spicules; upper 2 ft. fossiliferous. Fossils replaced by silica. Lowermost rock is a conglomerate with angular chert fragments.
BSC-18	6.8 ft.	Packstone: ramose bryozoans, brachiopods, sponge spicules; partial silica replacement of the fossils.
BSC-17	4 ft.	Packstone: brachiopods and sponge spicules; dolomitic; lowermost part very sandy.
BSC-16	5.5 ft.	Dolomite: sandy, fossiliferous, phosphatic forams; sponge spicules.
BSC-15	10.5 ft.	Sandstone: some chert and phosphatic grains; dolomitic.
BSC-14	4.5 ft.	Mudstone: dolomite, silty, possibly discontinuous algae mats.
BSC-13	8.5 ft.	Sandstone: chert and phosphatic grains; dolomitic.
BSC-12	14.5 ft.	Packstone: ramose bryozoans, brachiopods; dolomite rhombs; partial silicification, some scattered chert nodules.
BSC-11	2 ft.	Packstone: abundant sponge spicules, dolomitic.

BSC-10	5.8 ft.	Sandstone: some phosphatic grains, glauconitic; large dolomite rhombs; geodes of calcite are found. Silicified fossil fragments.
BSC-9	1.7 ft.	Dolomite: sandy.
BSC-8	8 ft.	Sandstone: a few phosphatic shell fragments and grains, chert grains; calcareous matrix at base of unit. Lower boundary is irregular.
BSC-7	1 ft.	Dolomite: burrowed, sandy.
BSC-6	2 ft.	Sandstone: phosphatic and chert grains; a few pellets; fine-grained dolomite matrix.
BSC-5	3 ft.	Wackestone: dolomite; sandy, burrowed and pelletal; silicified fossil fragments.
BSC-4	7 ft.	Sandstone: chert grains to 20%, and phosphatic grains; pelletal; a few fossil fragments. Irregular lower contact.
BSC-3	2.2 ft.	Dolomite: sandy, partly covered.
BSC-2	5 ft.	Packstone: phosphatic crinoid fragments, algal (phylloid?); pelecypods; pelletal; very porous, dolomitic.
BSC-1	11.3 ft.	Sandstone: abundant chert and phosphatic grains. Poorly sorted. Lower contact undulatory; and sand is intermixed with the underlying chert of the Rex Member.

Canyon Camp, NE$\frac{1}{4}$ sec. 18, T. 9 S., R. 3 W., sampled and measured by the writer in July 1971, on the south side of the Ruby River near the prospect pit.

Unit	Thickness	Description
Retort Member	---	Lowermost beds are mudstones.
Franson Member with tongues of the lower Shedhorn Member		
CCp-Rt-1 through Rt-7	8.5 ft.	Sandstone: the upper 4 ft. are calcareous; the lower 4.5 ft. are silicified. Lower boundary very irregular; intraclasts noticed.
CCp-1	2.5 ft.	Packstone: pelletal, mottled, and contains sponge spicules; slightly sandy and porous; fine laminated beds in lower part.
CCp-2	2.5 ft.	Chert: sandy, abundant sponge spicules; sand is found as interbeds.
CCp-3	1.5 ft.	Dolomite: silicified, contains sponge spicules and phosphatic grains; interbeds of sand.
CCp-4	2 ft.	Wackestone: pelletal, spicular dolomite; thin sandy layers; finely laminated.
CCp-5	1 ft.	Chert: upper $\frac{1}{2}$ ft. is dolomitic; lenses and nodules of chert intermixed with crossbedded sand layers.
CCp-6	4.5 ft.	Wackestone: pelletal, limey dolomite; thin laminations in middle part.
CCp-7	1.5 ft.	Dolomite: thick-bedded.
CCp-8	2 ft.	Sandstone: dolomitic; upper $\frac{1}{4}$ ft. is a thick dolomite.
CCp-9	13.5 ft.	Wackestone to Packstone: pelletal, finely laminated; lowermost oolitic and intraclastic; crinoid and pelecypod fragments; thick-bedded.

CCp-10	6 ft.	Sandstone: calcareous, laminated, scoured and cross-bedded.
CCp-11	7.5 ft.	Packstone: intraclastic and pelletal dolomite; silty; angular chert fragments in middle part; some phosphatic grains; upper part is a dolomitic mudstone.
CCp-12	.5 ft.	Mudstone: dolomitic, sandy, and contains some phosphatic crinoid fragments.
CCp-13	1 ft.	Same as CCp-12; burrowed.
CCp-14	13.5 ft.	Mudstone: dolomitic, silty, and contains phosphatic fragments; burrowed(?); middle portion is a pelletal wackestone; thick-bedded.
CCp-15	1.5 ft.	Siltstone: calcareous, thin-bedded, fine laminations.
CCp-16	10 ft.	Mudstone: silty, very fine laminations.
CCp-17	6 ft.	Covered.
CCp-18	9 ft.	Mudstone: silty, very fine laminations.
CCp-19	11 ft.	Sandstone: chert grains, dolomitic matrix; chert nodules and lenses abundant in the lower 7 ft.; covered below.

Canyon Creek #3, NW$\frac{1}{4}$ sec. 13, T. 2 S., R. 10 W., measured and sampled by the writer in August 1970. Section measured between the underlying Quadrant Formation and Retort Member. Grandeur and Franson Members are undifferentiated.

Unit	Thickness	Description
Retort Member	---	Phosphorites and mudstones.
Franson and Grandeur Members Undifferentiated		
CyC-1	0.7 ft.	Sandstone: phosphatic, chert and phosphate grains.

CyC-2	4.5 ft.	Packstone: sandy, limey dolomite; recrystallized brachiopod and pelecypod fragments.
CyC-3	6 ft.	Sandstone.
CyC-4	16.3 ft.	Packstone to Wackestone: intraclastic and pelletal; abundant sponge spicules and some crinoid fragments; abundant chert nodules, up to 35% of the unit in the lowermost part; dolomite is finely crystalline.
CyC-5	4.5 ft.	Dolomite: thick-bedded.
Covered	9.5 ft.	Dolomite float.
CyC-6	0.5 ft.	Mudstone: dolomite, sandy layers burrowed.
Covered	9.5 ft.	
CyC-7	5.5 ft.	Packstone: silicified bryozoan, brachiopod(?), and crinoid fragments; sponge spicules abundant, irregular chert nodules, and a few "boilerpipe" concretions.
CyC-8	11 ft.	Packstone: pelletal with fossil fragments; burrowed in places; sandy in lower foot; chert nodules are less abundant than CyC-7; dolomite.
CyC-9	2.5 ft.	Sandstone: bedded.
CyC-10	5.5 ft.	Covered.
CyC-11	2 ft.	Sandstone.
Covered	6.5 ft.	
CyC-12	7.5 ft.	Sandstone: underlain by massive Quadrant quartzite.

Cedar Creek, sec. 26, T. 9 S., R. 11 W., measured and sampled in June 1971, by the writer. Measured uphill from the bulldozer trench in the Retort Member.

Unit	Thickness	Description
Retort Member	---	Phosphorites and mudstones.
Franson Member		
CC-31	3.5 ft.	Sandstone: dolomitic; bedded, scoured, and burrowed; glauconitic; some sponge spicules; chert and phosphatic grains; uppermost part is oolitic.
CC-30	6.5 ft.	Dolomite: varies from sandy at the top to silty to a mudstone at the bottom; layered at the top to pelletal at bottom.
CC-29	37.5 ft.	Chert: sandy, it is sometimes a silicified sandstone.
CC-28	9.5 ft.	Dolomite: finely crystalline; burrowed; upper part contains some algal mats; covered in outcrop.
CC-27	4 ft.	Chert: 100% sponge spicules.
CC-26	13.5 ft.	Mudstone: silty to sandy, lower 4 ft. are chert.
CC-25	20 ft.	Mudstone: dolomitic; lower several ft. biofragmental, pelletal packstone which shows signs of burrowing.
CC-24	15 ft.	Sandstone: abundant chert grains and some phosphatic grains; an occasional dolomitic intraclast is seen.
CC-23	5 ft.	Sandstone: chert and phosphatic fragments.
CC-22	4 ft.	Sandstone: silicified; part of unit made of dolomite.
CC-21	1 ft.	Sandstone.

CC-20	13.5 ft.	Covered: chert in the upper 7 ft. made of sponge spicules; silty dolomite in the lower part.
CC-19	4.5 ft.	Chert: abundant sponge spicules; a few fish(?) fragments.
CC-18	22 ft.	Dolomite: sandy, burrowed; one sample was a laminated siltite; most of unit covered.
CC-17	10 ft.	Mudstone: dolomitic, sandy, contains a few sponge spicules.
CC-16	11 ft.	Sandstone: very dolomitic; lower 4 ft. are dolomite; burrowed, fish fragments(?), and an ostracod; chert and phosphate grains present.
CC-15	8.5 ft.	Sandy dolomite to a dolomitic sandstone.
CC-14	8.5 ft.	Packstone: pelletal, slightly porous, dolomite; parts are quite sandy, lowermost sample appears burrowed.
CC-13	6.5 ft.	Packstone: gastropod, _Plagioglypta_, ostracod, and siliceous fossil hash; pelletal, burrowed dolomite; one sample appears to be a boundstone of algal mats.
CC-12	5.5 ft.	Sandstone: dolomitic matrix; abundant chert and phosphatic grains.
CC-11	3. ft.	Chert: sandy.
CC-10	4 ft.	Sandstone: chert fragments, silicified.
CC-9	5.5 ft.	Chert: quite sandy; lower contact undulates up to 1½ ft. of relief, with sandstone layer at contact.

<u>Rex Member</u>

CC-8	2 ft.	Chert: sandy.

Meade Peak Member (?)

CC-7	1 ft.	Mudstone: phosphatic, pelletal(?).
CC-6	2 ft.	Chert.
CC-5	15 ft.	Covered.

Grandeur Member

CC-4	3.5 ft.	Dolomite: siliceous.
CC-3	5.5 ft.	Chert: dolomitic.
CC-2	8 ft.	Limestone: irregular chert lenses; irregular lower contact; upper 5 ft. are covered.
CC-1	9 ft.	Dolomite: lower contact covered. 120 ft. covered interval to first outcrop of Quadrant.

Daly's Spur, T. 8 S., R. 10 W., measured on the west side of the Beaverhead River by the writer in June 1971.

Unit	Thickness	Description
Retort Member	---	Phosphorites and mudstones.
Franson Member		
DS-12	16 ft.	Sandstone: chert and phosphatic grains.
DS-11	3 ft.	Sandstone: similar to DS-12, lower foot is very cherty.
DS-10	5 ft.	Siltstone: silicified, contains some angular chert fragments.
DS-9	5 ft.	Chert: some of unit is a siltstone with angular chert fragments.
DS-8	16 ft.	Siltstone: 1 ft. of chert in middle of unit; scattered chert nodules and lenses.
DS-7	1 ft.	Sandstone: chert and phosphate grains.

DS-6	6 ft.	Chert: includes some silt and sandy layers and lenses.
DS-5	9 ft.	Sandstone: chert and phosphate grains; calcareous matrix; chert nodules and lenses throughout; a few "boilerpipe" concretions.
DS-4	3 ft.	Chert.
DS-3	2.5 ft.	Sandstone: crumbly sample.
DS-2	8.5 ft.	Siltstone: few chert lenses and beds.
DS-1	5 ft.	Sandstone: upper part is silty, and lower part is cherty; chert fragments in lower part; underlain by chert of the Rex Member.

Hawley Creek, NE¼ sec. 36, T. 16 N., R. 27 E., measured by Dr. J. A. Peterson and the writer in August 1971. Assigning member status to the rocks was impossible as most of the section was covered.

Unit	Thickness	Description
Beds measured below the Retort Member		
HC-6	30 ft.	Upper 5 ft. are a very sandy dolomite; middle 5 ft. are a fine-grained, phosphatic sandstone; lowermost part is a silty dolomite; rest of unit is covered.
HC-5	45 ft.	Covered: float is shaly to silty, with a few ledges of carbonate exposed.
HC-4	21 ft.	Covered: lowermost part is a silty, cherty dolomite, thin-bedded.
HC-3	33 ft.	Covered.
HC-2	30 ft.	Dolomite: thick-bedded.
HC-1	115 ft.	Covered: underlain by Quadrant quartzite.

Hogback Mountain, $S\frac{1}{2}$ $NW\frac{1}{4}$ sec. 8, T. 11 S., R. 4 W., measured and sampled by the writer in August 1971.

Unit	Thickness	Description
Retort Member	---	Phosphorites and mudstones.
Lower Shedhorn Sandstone Member	19.5 ft.	Sandstone: See Cressman and Swanson (1964); includes a 3.7 ft. unit of dolomite 4 ft. up from the underlying Franson Member.
Franson Member		
HM-1	10.5 ft.	Packstone: pelletal with some samples being of rounded intraclasts; finely crystalline dolomite.
HM-2	10 ft.	Sandstone: Bimodal (0.2mm and 0.06mm), scoured, thin bedded and platy.
HM-3	23 ft.	Wackestone: pelletal, with minor phosphatic fossil fragments; minor silt and sand; porous.
HM-4	7 ft.	Wackestone to Packstone: the upper 5 ft. are silty wackestone with phosphatic fossil fragments to 5%; burrowed and a few thin laminae; lower part is a sponge spicule packstone; dolomitic.
HM-5	2 ft.	Upper 1 ft. is a mudstone: silty, dolomitic, with 10% phosphatic fossils; the lower 1 ft. is a packstone: with sponge spicules, phosphatic pellets, and intraclasts.
HM-6	10 ft.	Siltstone to a mudstone: dolomitic, upper 1 ft. contains phosphatic fossil fragments, in a siltstone, which is laminated and burrowed; lowermost ft. is a silty mudstone, dolomitic; sponge spicules present along with chert nodules in the lower 9 ft.

HM-7	45 ft.	Mudstone to Packstone: dolomite; mudstone accounts for the upper 2 ft. where it contains many sponge spicules, and the lower 5 ft; 2 ft. from the upper boundary is a 1 ft. thick bed of sandstone; the rest of the unit is a packstone; pelletal, or more often intraclastic; fossils include bryozoans, red algae(?), algal blades (phylloids?), gastropods; many fossils have been leached, and most of this unit is very porous.
HM-8	8 ft.	Sandstone: dolomitic, thin bedded, with wavy laminae; probably tongue of the lower Shedhorn Member.
HM-9	13 ft.	Mudstone: silty to sandy, laminated bedding in the lower part, microcrystalline dolomite; contains some phosphatic fossil fragments; lower contact with chert of the Rex Member is undulatory; lowermost Franson is a thin sand layer.

Kelly Gulch, sec. 2, T. 6 S., R. 11 W., measured and sampled by the writer in October 1971.

Unit	Thickness	Description
Retort Member	---	Phosphorites and mudstones.
Franson Member		
KG-4	11.5 ft.	Dolomite: siliceous fossils, slightly sandy; abundant chert lenses, nodules, and beds; lowermost is sandy.
KG-3	16 ft.	Sandstone: chert grains, scattered sponge spicules; dolomitic and siliceous matrix occasionally.
KG-2	18.5 ft.	Dolomite: sandy, burrowed and occasionally pelletal; chert and sand often found as vertical concretions.

KG-1	7.5 ft.	Dolomite: many angular chert fragments, especially in the lower part; sand lenses are intermixed; contact with underlying Meade Peak Member is covered.

LaMarche Gulch, sec. 32, T. 1 S., R. 9 W., measured on the west side of the Big Hole River by Rodney Shepherd and the writer in August 1970.

Unit	Thickness	Description
Retort Member	---	Phosphorites and mudstones. The lower contact is conglomeratic.
Franson Member		
LG-27	9 ft.	Packstone: upper 2 ft. contains crinoids, pelecypods, ostracods, algal (phylloid?), and pelletal dolomite; lower 7 ft. are pelletal, burrowed and silty.
LG-26	3 ft.	Chert.
LG-25	2 ft.	Packstone: pelletal, intraclastic, grapestone; contains a layer of shaly partings.
LG-24	2.5 ft.	Dolomite: silty, crinoid fragments.
LG-23	2 ft.	Mudstone: silty; lower boundary is undulating.
LG-22	1.5 ft.	Sandstone: bedded.
LG-21	1 ft.	Packstone: intraclastic.
LG-20	21 ft.	Packstone: abundant ostracods; gastropods, phosphatic crinoids, pelletal; dolomite; lower 4 ft. is a dolomitic mudstone; the unit contains 3 thin beds of shaly partings.
LG-19	4.5 ft.	Wackestone: pelletal, burrowed sandy, and contains up to 15% phosphatic chamber-filled fossils; separated from unit below by a shaly parting.

LG-18	1.5 ft.	Dolomite: sandy, chert grains.
LG-17	2.5 ft.	Sandstone: many chert grains, dolomitic; lowermost part is a conglomerate of chert and dolomitic intraclasts, and sponge spicules; chert nodules.
LG-16	15 ft.	Packstone: sponge spicules, dolomitic, chert nodules.
LG-15	3.5 ft.	Mudstone: sandy, sponge spicules, contains a chert bed.
LG-14	2 ft.	Dolomite: contains chert nodules.
LG-13	11.5 ft.	Sandstone: very fine dolomitic matrix, chert nodules.
LG-12	34 ft.	Mudstone: occasionally pelletal and burrowed; dolomitic, contains sponge spicules; many chert nodules and lenses.
LG-11	2 ft.	Sandstone: many cherty nodules.
LG-10	2 ft.	Dolomite: slightly sandy, chert nodules.
LG-9	4 ft.	Sandstone: dolomitic; upper half is a sandy dolomite.
LG-8	1.5 ft.	Sandstone.
LG-7	3 ft.	Wackestone: pelletal, intraclastic; sandy and cherty; chert nodules.
LG-6	3.5 ft.	Dolomite: sandy, burrowed.
LG-5	1 ft.	Sandstone: dolomitic.
LG-4	2 ft.	Dolomite: sandy, pelletal.
LG-3	4.5 ft.	Sandstone: calcareous.
LG-2	6 ft.	Sandstone: dolomitic, burrowed.
LG-1	1.5 ft.	Sandstone: underlain by the Pennsylvanian Quadrant Formation.

Lazyman Hill, sec. 9, T. 10 S., R. 2 W. The four carbonate units within the lower Shedhorn Member and Rex Chert Member sampled by the writer, July 1971. See Cressman and Swanson, (1964), for thicknesses of the remainder of the Phosphoria Formation.

Unit	Thickness	Description
LMH-4	1.2 ft.	Mudstone: slightly mottled, fine-grained.
LMH-3	2.5 ft.	Limestone: very sandy.
LMH-2	1.2 ft.	Wackestone: pelletal, burrowed, sponge spicules, sandy and dolomitic.
LMH-1	0.8 ft.	Mudstone: sponge spicules and dolomitic.

Little Sheep Creek, SW¼ sec. 34, T. 14 S., R. 9 W., was measured and sampled by the writer in June 1971.

Unit	Thickness	Description
Retort Member	---	Phosphorite; lower contact with Franson possibly erosional, conglomeratic.
Franson Member		
LSC-16	27 ft.	Packstone: ramose bryozoan, crinoidal fragments, and sponge spicules; upper 10 ft. becomes sandier; phosphate grains plus phosphatic chamber fillings of bryozoans; some samples are partially silicified.
LSC-15	13.5 ft.	Packstone: crinoid fragments and a few ramose bryozoans, sandy, dolomitic; sponge spicules are common; the lower 3 ft. is a silty sandstone.
LSC-14	16.5 ft.	Chert and dolomite intermixed; conspicuous sponge spicules, silty; dolomite commonly forms large rhombs; chert as layers, lenses and interbeds.

LSC-13	1 ft.	Siltstone: siliceous matrix.
LSC-12	1.5 ft.	Siltstone: dolomitic, sponge spicules.
LSC-11	16.5 ft.	Dolomite: contains large rhombs and overgrowths; moderately silty, siliceous matrix common.
LSC-10	11 ft.	Siltstone: dolomitic, bedded, contains a few crinoid fragments.
LSC-9	12 ft.	Covered: upper 11 ft.; lower 1 ft. is a sandstone; chert grains and 10% phosphatic grains; glauconitic; bryozoan and a few brachiopod fragments.
LSC-8	10 ft.	Packstone: ramose bryozoans, productid brachiopods, and a few crinoids; sandy, dolomite rhombs, and a few sponge spicules; the lower 5 ft. contains abundant chert lenses, beds, nodules, lots of sponge spicules, and a reduced fauna containing only a few bryozoans.
LSC-7	6 ft.	Packstone: ramose bryozoans, productid brachiopods, and a few crinoids; sandy, dolomitic, glauconitic, minor sponge spicules.

Interval below was covered: footage and description taken from Cressman and Swanson (1964).

LSC-6	4.7 ft.	Limestone: skeletal, thick-bedded.
LSC-5	7.0 ft.	Dolomite: skeletal, thick-bedded.
LSC-4	4.0 ft.	Dolomite: skeletal, thick-bedded.
LSC-3	12.0 ft.	Dolomite: thick-bedded, aphanitic.
LSC-2	12.0 ft.	Dolomite: thick-bedded, aphanitic.
LSC-1	4.5 ft.	Sandstone: fine-grained; underlain by 30 ft. of covered interval to the first outcrop of Rex Chert.

Little Water Canyon, SE¼ sec. 4, T. 13 S., R. 10 W., measured and sampled by the writer in July 1971. The upper 40 ft. is an approximate distance as much is poorly exposed with poor control.

Unit	Thickness	Description
Retort Member	---	Phosphorites and sandstones.
Franson Member		
LW-13	4 ft.	Sandstone: chert and phosphatic grains (35%); glauconitic, some fossil fragments.
LW-12	3.5 ft.	Packstone: abundant ramose bryozoans and crinoid fragments; glauconite; limestone; phosphatic grains and fragments.
LW-11	7 ft.	Wackestone: bryozoan and crinoid fragments; sponge spicules; dolomite; part of unit is a sandstone.
LW-10	10.5 ft.	Sandstone to Packstone: crinoid and bryozoan fragments, sponge spicules, dolomitic.
LW-9	20 ft.	Packstone: ramose bryozoans, productid brachiopods, crinoid fragments, and sponge spicules, dolomite seen as rhombs and overgrowths, highly silicified.
LW-8	13 ft.	Packstone: crinoid and brachiopod fragments in the upper 2 ft. sponge spicules abundant; dolomite as rhombs and overgrowths; most of unit is silicified; chert as nodules, lenses and irregular masses.
LW-7	9 ft.	Mudstone: very silty, dolomite as rhombs and overgrowths; sponge spicules minor; unit partially covered.
LW-6	15 ft.	Siltstone: dolomitic; sponge spicules in upper part, unit partially covered.

LW-5	14.5 ft.	Sandstone: glauconitic, dolomitic matrix; interbeds of pelletal dolomite, scattered brachiopod and crinoid fragments.
LW-4	1 ft.	Mudstone: sandy, dolomite.
LW-3	22.5 ft.	Sandstone: chert (about 10%) and phosphatic (10%) grains, a few phosphatic crinoid fragments, dolomitic matrix; calcite fossil fragments scattered throughout this unit.
LW-2	8.5 ft.	Packstone to Wackestone: pelecypods, algal (phylloid?); phosphatic crinoids, brachiopods, and ostracods, pelletal; dolomite.
LW-1	13 ft.	Sandstone: chert (5%) and phosphatic (4%) grains; brachiopod and crinoid fragments, dolomitic matrix; irregular, intermixed boundary with underlying chert of the Rex Member.

North Big Hole Canyon, NE¼ sec. 3, T. 5 S., R. 8 W., measured by the writer and Rodney Shepherd in August 1970.

Unit	Thickness	Description
Lower Shedhorn Member		
NBH-40	10 ft.	Sandstone: upper contact with Retort is obscured by rubble; undulating contact with underlying Franson Member, with relief from 3 to 5 ft.; spicules and silicified matrix.
Franson Member		
NBH-39	6.5 ft.	Sandstone: chert and phosphatic grains; calcareous matrix, upper 2 ft. are made also of dolomitic intraclasts and grapestones; sponge spicules.
NBH-38	5 ft.	Covered.

NBH-37	3 ft.	Chert: sandy, abundant spicules, phosphatic-filled gastropod; sharp, undulating underlying boundary.
NBH-36	8 ft.	Packstone to Wackestone: intraclastic to pelletal, dolomitic, mostly microcrystalline; phosphatic fragments; some sponge spicules.
NBH-35	3 ft.	Covered: shaly siltstone and phosphorite.
NBH-34	2.5 ft.	Chert: lower contact undulating.
NBH-33	10 ft.	Packstone: phosphatic and dolomitic intraclasts, silicified, with sponge spicules.
NBH-32	14 ft.	Covered.
<u>Rex Chert Member</u>		
NBH-31	3 ft.	Chert.
<u>Meade Peak Member</u>		
NBH-30	17.5 ft.	Phosphorites and mudstones.
<u>Grandeur Member</u>		
NBH-29	7.5 ft.	Dolomite: with much silica replacement; abundant chert nodules.
NBH-28	10 ft.	Covered.
NBH-27	2.5 ft.	Dolomite: microcrystalline; chert nodules, and sponge spicules.
NBH-26	2.5 ft.	Limestone: crystalline, porous.
NBH-25	4 ft.	Limestone: silty, porous.
NBH-24	8 ft.	Covered.
NBH-23	2 ft.	Dolomite: silty.
NBH-22	2.5 ft.	Covered.

NBH-21	5.5 ft.	Wackestone: silty, pelletal, sponge spicules, dolomite.
NBH-20	2.5 ft.	Covered.
NBH-19	1 ft.	Sandstone: sponge spicules, fish fragments parallel to bedding, glauconite.
NBH-18	10 ft.	Wackestone to Packstone: intraclastic to pelletal, dolomite; some sponge spicules.
NBH-17	0.5 ft.	Chert: dolomitic.
NBH-16	0.5 ft.	Dolomite: silty, pelletal, sponge spicules.
NBH-15	11.5 ft.	Covered: with some sandstone and siltstone beds.
NBH-14	13.5 ft.	Covered: lower $1\frac{1}{2}$ ft. chert with undulating lower contact.
NBH-13	1.5 ft.	Limestone.
NBH-12	0.5 ft.	Shaly, dolomitic mudstone.
NBH-11	2 ft.	Dolomite: sponge spicules.
NBH-10	0.5 ft.	Dolomite: silty.
NBH-9	2 ft.	Dolomite: silty, some dolomite rhombs.
NBH-8	1.5 ft.	Dolomite: with rhombohedral overgrowths.
NBH-7	0.5 ft.	Dolomite: sandy.
NBH-6	4.5 ft.	Covered: dolomitic mudstone at upper contact.
NBH-5	0.5 ft.	Dolomite.
NBH-4	1 ft.	Chert.
NBH-3	7 ft.	Limestone: chert nodules and lenses in middle portion.

NBH-2	4.5 ft.	Limestone: sandy.

<u>Quadrant Formation</u>

NBH-1	---	Sandstone: calcareous.

Sawtooth Mountain, NE$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 10 T. 12 S., R. 5 W., measured and sampled by the writer in August 1971.

Unit	Thickness	Description
Retort Member	---	Phosphorites and mudstones.
Lower Shedhorn Member		
STM-SH-5	3 ft.	Chert: sandy; 90% indentifiable sponge spicules; phosphatic matrix.
STM-SH-4	7.5 ft.	Sandstone: chert and phosphatic grains abundant.
STM-SH-3	3.5 ft.	Sandstone: similar to SH-4.
STM-SH-2	3.5 ft.	Sandstone: similar to SH-4.
STM-SH-1	3 ft.	Sandstone and chert intermixed.
Franson Member		
STM-20	2 ft.	Chert and silty shale: phosphatic fragments, sandy.
STM-19	0.8 ft.	Conglomerate: made of chert fragments from unit STM-18; grades upward to a phosphatic sandstone with abundant chert fragments.
STM-18	5.5 ft.	Chert: sandy, thin-bedded and banded; abundant sponge spicules.
STM-17	26 ft.	Wackestone: silty, pelletal (partially destroyed by dolomitization), porous, dolomite; lower few feet is a dolomitic siltstone, finely laminated.
STM-16	7 ft.	Sandstone: very fine-grained, very porous, banding accentuated by opaque minerals.

STM-15	11 ft.	Wackestone: pelletal, silty, burrowed; dolomite; very porous; middle part has abundant fossil fragments, most of which have been leached.
STM-14	9.5 ft.	Mudstone to Wackestone: silty to sandy, phosphatic fossil fragments, pelletal and burrowed; middle part of unit is a mudstone; thick-bedded, dolomite.
STM-13	1.5 ft.	Packstone: sponge spicules, sandy.
STM-12	3 ft.	Wackestone: abundant phosphatic fossil fragments including bryozoan and foram; very silty; fossils accentuate bedding.
STM-11	16.5 ft.	Packstone: pelletal and some intraclasts, with abundant sponge spicules in upper half; dolomite; uppermost part contains phosphatic fossil fragments; silty.
STM-10	1 ft.	Dolomite: silty or sandy, phosphatic fossil fragments; thin laminations.
STM-9	5 ft.	Mudstone: silty, dolomitic; cherty matrix; chert nodules in lower part.
STM-8	10.5 ft.	Wackestone to Mudstone: pelletal and porous; 5% phosphatic fossil fragments; silty; sponge spicules.
STM-7	8 ft.	Packstone: intraclastic and very porous; dolomite; fossil-fragmental including bryozoans, forams, and ostracods; 5% phosphatic fossil fragments.
STM-6	11 ft.	Packstone to Wackestone: bryozoans, ostracods; pelletal, dolomitic wackestone is in the middle of the unit; the rest is packstone: intraclastic, "grapestone",

STM-5	1 ft.	Wackestone: silty, pelletal, 2% phosphatic fossil fragments.
STM-4	8 ft.	Packstone: pelletal and burrowed dolomite; upper 6 ft. are a dolomitic mudstone.
STM-3	6.5 ft.	Packstone: pelletal dolomite in upper half of unit; sandy, intraclastic, bedded and burrowed in lower half.
STM-2	5.5 ft.	Sandstone: bedded, burrowed, bimodal, dolomitic; platy and thin-bedded.
STM-1	5 ft.	Wackestone: silty, laminated, scoured, pelletal, algal mats, dolomite; some scattered chert nodules and sponge spicules; contact with underlying Rex Member covered.

Sheep Creek, NW¼ SW¼, sec. 23, T. 9 S., R. 9 W., measured and sampled by the writer in July 1971. Most of the middle portion of the Franson Member was covered in a bulldozer trench and samples were taken by digging holes to the bedrock.

Unit	Thickness	Description
Retort Member	---	Phosphorites and mudstones.
Franson Member		
SC-5	35 ft.	Sandstone: weathered, poorly sorted, chert and phosphatic grains; crinoid, bryozoan and foram fossils; the uppermost foot is oolitic, and contains intraclasts; the lower 20 ft. are silty chert of silicified siltstone.
SC-4	29.5 ft.	Chert: abundant spicules, very silty, some samples are a siliceous siltstone.
SC-3	2 ft.	Chert.

SC-2	47 ft.	Mudstone: dolomitic; vaguely pelletal, somewhat porous; minor chert nodules; a few phosphatic crinoid fragments.
SC-1	5 ft.	Sandstone: silicified, phosphatic crinoid fragments, chert grains.
SC-R1 to R3	6 ft.	Sandstone: abundant chert and phosphatic grains, silicified.

Sliderock Mountain, $N\frac{1}{2}$ sec. 25, T. 10 S., R. 4 W., measured by the writer in August 1971.

Unit	Thickness	Description
Retort Member	---	Phosphorites and mudstones.
Lower Shedhorn Member	15 ft.	Sandstone.
Franson Member		
SR-1	4 ft.	Chert: sandy, abundant sponge spicules, and some phosphatic fragments.
SR-2	8 ft.	Packstone: pelletal dolomite; silty to sandy, the upper 1 ft. is a sandstone; phosphatic and chert grains.
SR-3	5 ft.	Packstone to Mudstone: intraclastic to pelletal packstone in upper 3 ft. of the unit, dolomitic; lower 2 ft. are a dolomitic mudstone; sponge spicules; abundant chert nodules and irregular masses.
SR-4	10 ft.	Wackestone to Packstone: pelletal, silty, dolomite; $\frac{1}{2}$ ft. of chert 3 ft. above bottom; abundant chert masses and nodules.
SR-5	13 ft.	Packstone: pelletal, silty dolomite; 4 ft. down from the top of the unit, it is an intraclastic, oolitic (with quartz nuclei) packstone; lowermost part contains abundant sponge spicules.